Report of the 3rd working group meeting on optimization of fishing pressure in the Northeast Atlantic, Rhode Island March 2018: Project: Ecosystem Based FMSY Values in Fisheries Management

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Project: Ecosystem Based FMSY Values in Fisheries Management

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Project: Ecosystem Based FMSY Values in Fisheries Management

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The European Maritime and Fisheries Fund & the Danish Ministry of Environment and Food (1.372 mio DKK), the Norwegian Fisheries Research Fund via IMR Norway (0.5 mio DKK) and from the Nordic Council of Ministers (0.5 mio DKK). The total budget for the project is therefore 3.057 mio DKK.

Meeting 12 -14 March 2018,

Rhode Island, USA

Venue: Bay Campus, University of Rhode Island, Kingston, RI 02881, USA

Ministry of Environment and Food of Denmark

European Union
European Maritime and Fisheries Fund

Nordic Council of Ministers

INSTITUTE OF MARINE RESEARCH

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Introduction

The participants of the project “Ecosystem Based FMSY Values in Fisheries Management”, in short, the “FMSY project”, meet for the third time. The meeting took place at the facilities of the Bay Campus, University of Rhode Island, Narragansett, RI 02881, USA, 12-14 March 2018. An Agenda for the meeting was send out beforehand, and is given in Appendix 1. The agenda was adopted. The list of participants are given in Appendix 2. The present report is a Minutes report of the meeting.

The meeting benefitted greatly from having Steven Cadrin, Mike Fogarty, John Pope, as well as graduate student, Joseph Zottoli and post doc, Adrien Tableau, from the University of Rhode Island, participating.

1. The list of stocks

The stocks to be included in the current project are data rich stocks from the Northeast Atlantic supplemented with stocks from the Northwest Atlantic. Table 1.1 gives the current list.

Table 1.1. The estimates of Fmsy from ICES and from methods that include density-dependent effects in growth, maturity and/or mortality in addition to that based on a stock recruitment relationship. The “currency” for F used is the ICES ones from 2016, e.g. for North Sea cod the mean F at age 2-4. Only stocks with time series of at least 30 years and F expressed in absolute terms (not in relative terms to a mean F or to an Fmsy) like rate per year, are included. Yellow potential new stocks. Orange stocks to go out (mainly due to too short time series, whiting out due to recognized problems of either a lot of unreported industrial catches or discards, and severe inconsistencies to the IBTS survey which is very precise for whiting at least in the North Sea, and spasmodic recruitment).

			Fmsy							
Stock		ICES 2016	Froese *et al.* SPM	RAM Legacy Db	Eco-system model 1	Eco-system model 2	Eco-system model 3	ASPIC	PROST	XX?
Comment number\letter		a	b	c	d	e	f	g	h	i
Blue whiting	1	0.32	0.37							
Cod Icelandic	2	-	0.63							
Cod W Scotland	3	0.17	-							
Cod Irish Sea	4	0.37	0.95							
Cod (*Gadus morhua*) in divisions 7.e–k (western English Channel and southern Celtic Seas)	5	0.35	0.56							
Cod North Sea	6	0.33	0.70		0.89					
Cod Northeast Arctic	7	0.40	0.55							

Cod Faroe Plateau	8	0.32	0.36								
Cod Western Baltic Sea	9	0.26	0.62								
Cod Eastern Baltic Sea	10	-	-		0.87						
Haddock Icelandic	11	-	0.47								
Haddock Faroe	12	0.25	0.28								
Haddock Rockall	13	0.20	0.31								
Haddock Irish Sea	14	0.27	0.41								
Haddock VIIb-k	15	0.40	0.87								
Haddock North Sea	16	0.19	-		0.52						
Haddock Northeast Arctic	17	0.35	0.43								
Hake Northern	18	0.28	0.82								
Hake Southern	19	0.25	0.59								
Herring Western Baltic	20	0.32	0.33								
Herring Icelandic	21	0.22	0.23								
Herring W Scotland and W Ireland	22	0.16	0.22								
Herring Irish Sea	23	0.26	0.43								
Herring Celtic Sea and South of Ireland	24	0.26	0.34								
Herring North Sea	26	0.33	0.58		0.50						
Herring Norwegian SSP	27	0.15	-								
Herring Gulf of Riga	28	0.32	0.34								
Herring Bothnian Sea	29	0.15	-								
Herring 25–29, 32 xGoR	30	0.22	-		0.35						
Horse mackerel W	31	0.13	-								
Mackerel	32	0.22	0.36								
Plaice E Channel	34	0.25	0.27								
Plaice Kattegat Sund	38	0.37	0.55								
Plaice North Sea	39	0.19	0.47								
Saithe Icelandic	40	-	0.31								
Saithe Faroe	41	0.30	0.37								
Saithe North Sea etc.	42	0.36	0.54		0.33						
Saithe Northeast Arctic	43	-	0.49								
Sole Irish Sea	44	0.20	0.18								
Sole Eastern Channel	45	0.30	0.48								
Sole Western Channel	46	0.29	0.26								
Sole Bristol Chanel Celtic Sea	47	0.27	0.31								
Sole Kattegat	48	0.23	0.38								
Sole Bay of Biscay	49	0.33	0.43								
Sole North Sea	50	0.20	0.38								
Sprat Baltic Sea	51	0.26	0.42							0.45	
Whiting W of Scotland	52	0.18	0.21								
Whiting VIIe-k	53	0.52	0.54								
Whiting North Sea	54	0.15	0.22		0.25						

Golden redfish Iceland										
Sandeel Sa 1										
Sandeel Sa 2										
Sandeel Sa 3										
Striped bass (USA east coastal waters)										
Summer flounder (USA east coastal waters)										
Menhaden US Eastcoast										

Table 1.1 Footnotes: Each cell in the table have an identifier, the top left one 1a and the bottom right one 61i. The comments below are linked to the cells in the table by these identifiers.

1a-54a: ICES Fmsy from ACOM 2015. "-" means not available, i.e. no Fmsy defined.

1b-54b: Fmsy from Froese et al 2016 translated into the F-unit used by ICES typically the mean F over some core exploited age groups. Based on Froese et al F/Fmsy from Surplus production models, divided by ICES actual F values from assessments. Mean values over 2000-2012.

3b: Stock not well defined, extremely small in recent years, unreliable catch data due to area misreporting historically, mainly discards in the past 8 years. No need for an Fmsy the coming 5 years until the stock has rebuild.

10b. Baltic cod in SD 2532 a major outbreak of a disease likely due to parasite infestation due

10d, 30d, 51d: Most complete model: Multispecies FMSY Gislason (1999). The options assuming constant relationship in F between the three stocks (that of 1996).

16b. Spasmodic recruitment and thus not suitable for SPM.

29b. This stock (herring SD30) has increased by a factor of 4 in the past 4 decades and so has the catch. Thus, surplus production modelling dubious.

6d, 16d, 26d, 42d, 54d: Most complete model: Multispecies FMSY (Collie et al 2003). Figure 4 and Table 2, combined.

31b. Spasmodic recruitment and thus not suitable for SPM.

51h: From J. Horbowy and A. Luzenczyk. 2016. Effects of multispecies and density-dependent factors on MSY reference points: example of the Baltic Sea sprat. Can. J. Fish. Aquat. Sci. 00: 1–7 (0000) dx.doi.org/10.1139/cjfas-2016-0220. Option with density dependence in growth and mortality, and cod (age 2+) biomass 200 000 t. Cod biomass probably a bit lower the coming 5 years, but the analysis was only sensitive to larger cod biomass.

27b. A few very large year classes. Exploitation pattern changed at lot over time. A large 0 and 1 group fishery in the 1970s.

30b. Stock not well defined and predation probably high in the 1980s when the cod stock was very high.

51b. Sprat predation mortality was very high in the 1980s when the cod stocks was very high.

52b. Stock not well defined.

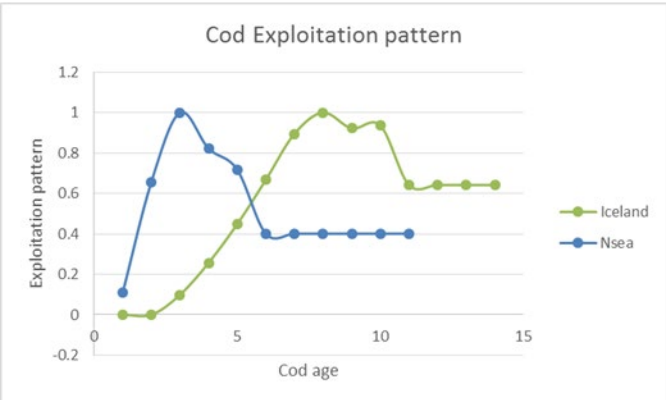
…

2. Progress on Work Packages

The work packages were discussed one by one.

2.1 WP1 The ”common currency” problem for fishing mortality

A suggestion for text for the final project report was presented at the previous meeting (see the Vancouver meeting report, Appendix 4). Since then, further tests were made. North Sea cod and cod at Iceland are expected to differ most as the mesh size used and therefore the resulting exploitation pattern differ a lot (Figure 2.1.1).



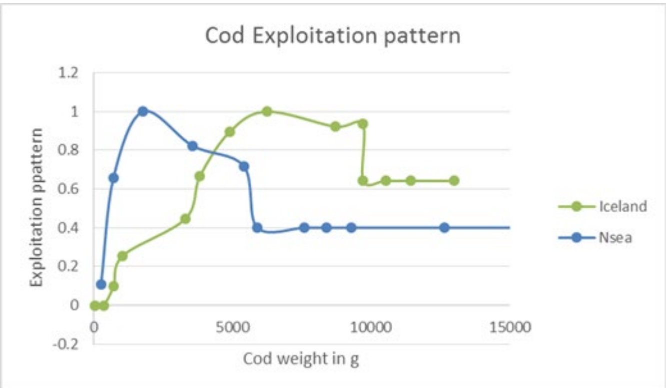
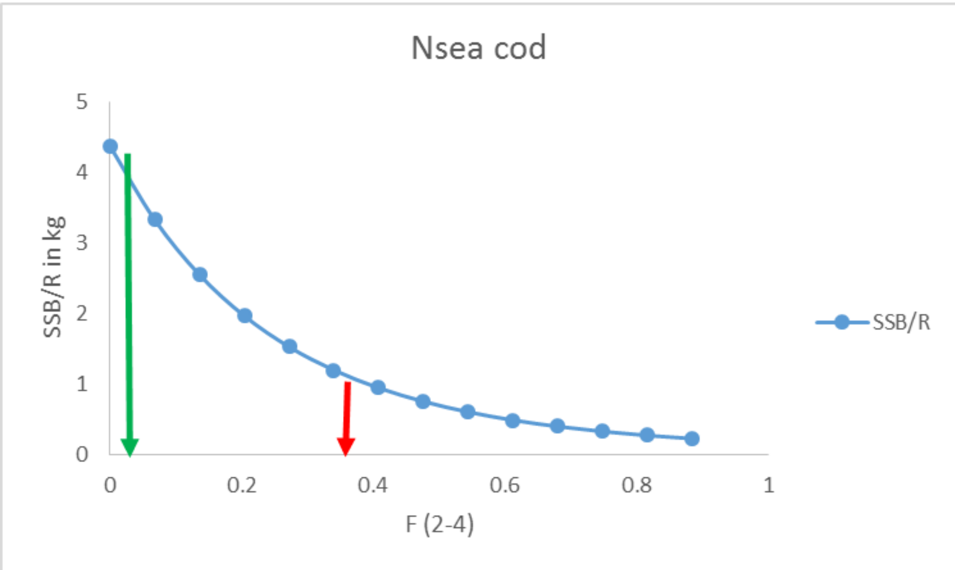


Figure 2.1.1 *Comparison between exploitation pattern in the North Sea cod fishery and the cod at Iceland fishery. In the top panel expressed as age based F and in the bottom panel as size based (From ICES WG reports).*

However, when expressed as its influence on the stocks in terms of the F metric (1-SPR) (see text box below) the difference are very small (see below) and therefore Fmsy for the two stocks are directly comparable, it seems.

Text Box.

For a given fishing pattern, SPR(F) is the ratio of SSB per recruit, when fishing at an intensity of F, divided by the SSB per recruit with no fishing (Goodyear, 1993 and Cordue, 2012). In the usual notation, if a fishing intensity F has an SPR of x%, then the intensity is denoted as Fx% (e.g. Clark, 2002). From the definition of SPR, it follows, for a given fishing pattern, that under constant virgin recruitment, the fishing intensity, Fx%, will produce an equilibrium SSB of x%B0. Often the final metric is calculated as 1 – SPR(F) [called (1-SPR)], because it then is an increasing function of fishing intensity. Thus, (1-SPR) is "1- ratio of (SSB/R at F) to (SSB/R at F=0) ". The figure below illustrates the concept of (1-SPR) with data from the North Sea cod stock.



The effect of a hypothetical mesh size increase for the North Sea cod fishery, resulting in a shift in exploitation pattern one age down, meaning that F-at-age 1 becomes F-at-age 2, F-at-age 2 becomes F-at-age 3 etc., is shown in Figure 2.1.2. This results in an increase in the Fmsy from 0.35 to 0.43 (measured as a mean over ages 2-4), but when expressed in $(1\text{-SPR})_{msy}$ it only changed from 0.74 to 0.77. So, even in the sensitive part of the F scale for (1-SPR) a quite small change, indicating that (1-SPR) is a good way of comparing MSY values across stocks, with similar population dynamics, but different exploitation pattern.

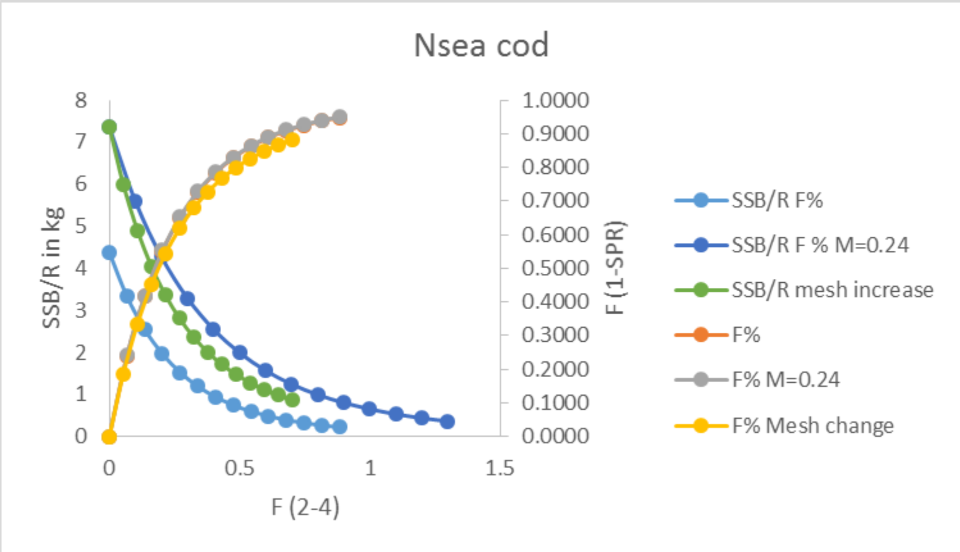


Figure 2.1.2 *The relationship between an ordinary average F over age groups and the F metric calculated as (1-SPR) for North Sea cod where the red line is with M1+M2 (almost completely hidden by the grey line), the grey line with M=0.24 for all age groups, and the yellow line for a mesh size increase corresponding to a shift in exploitation pattern by one age group so that F at age 1 becomes 0.0, F at age 2 become the former F at age 1, F at age 3 the former F at age 2, etc. M for the yellow line scenario is 0.24 for all ages.*

The issue of different M-at-age arrays used in the calculations of Fmsy was also tested with North Sea cod as an example. Here the M values given in Table 2.1.1 were compared. The results can be seen in Figure 2.1.2. Even though the SSB/R differ a lot as expected, the (1-SPR) does not differ almost at all (the red line is hidden beneath the grey line in the plot).

Table 2.1.1 *Set of natural mortality M values used in the scenario calculations for North Sea cod. M1+M2 is called the base case and is what ICES use in its routine assessments.*

Age	M1+M2 per year	M per year
1	0.56	0.24
2	0.38	0.24
3	0.28	0.24

4	0.26	0.24
5	0.25	0.24
6	0.24	0.24
7+	0.24	0.24

However, the F on the x-axis differ slightly and it might be more illustrative to plot the results as the Yield vs (1-SPR) so that (1-SPR)msy is considered directly. Figure 2.1.3 shows these plots for North Sea cod. The (1-SPR)msy varied from 0.73 for the constant M=0.24 scenario, to 0.76 for the constant M=0.24 and mesh size increase scenario, to 0.83 for the base case scenario. So, some sensitivity to variation in the M array, but robust to a mesh size change.

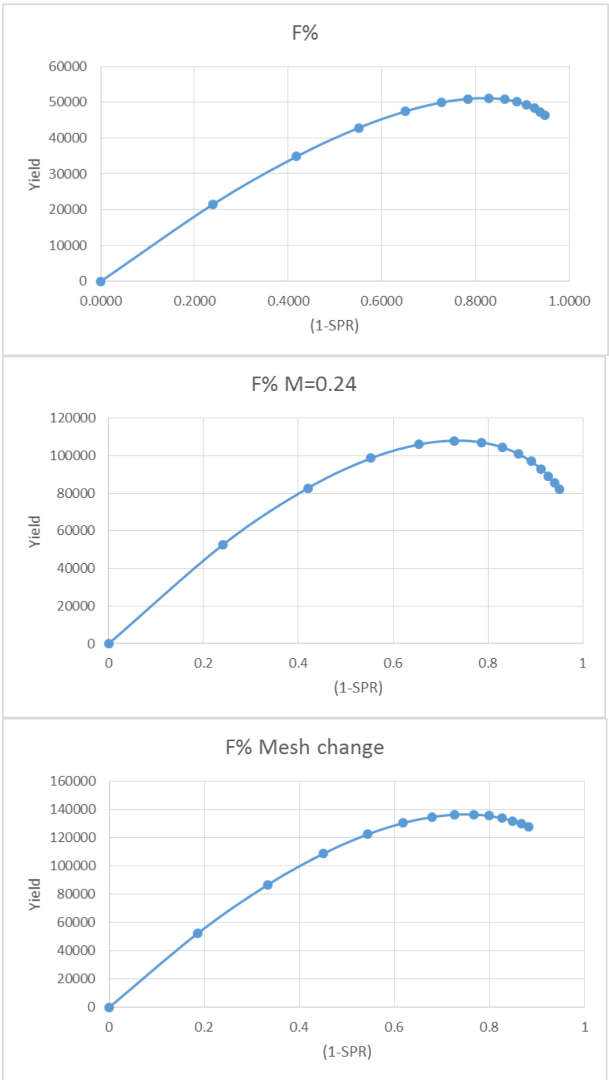


Figure 2.1.3. *North Sea cod. The sensitivity of (1-SPR)msy to M at age used and mesh size changes. Top panel based on ICES (2017) data, middle panel, M=0.24 for all ages, and bottom panel M=0.24 and exploitation pattern shifted one age group "down" simulating a mesh size increase.*

In conclusion (1-SPR) seems to be a suitable metric for fishing pressure for meta-analysis of the fishing pressure that gives MSY, but that care had to be taken if stocks are inconsistent with regard to the M values used in the calculations. Thus, for those stocks where we “know” Fmsy from multispecies and ecosystem models, these will have to be translated into an (1-SPR)msy by way of the relationship between (1-SPR) and F-at-age by stock, as shown in Figure 2.1.3, before used in a meta-analysis. The resultant (1-spr)msy for those stocks which do not have an Fmsy estimate from multispecies and ecosystem models, needs to be translated back to F-at-age by stock. Thus, plots like Figure 2.1.3 need to be made for all stocks considered in the present project.

A comparison was made between North Sea cod and Icelandic cod in terms of F age 2-4 for North Sea cod and F age 5-10 for Icelandic cod in order to see if these F metric could be compared directly. The basic idea is that if for the same 1-SPR for the two stock how different are then the corresponding Fage2-4 (for North Sea cod) and Fage5-10 (for Icelandic cod). Surprisingly, they are almost identical, see Figure 2.1.4. This means that there is no need to convert to a “common currency” F in this case.

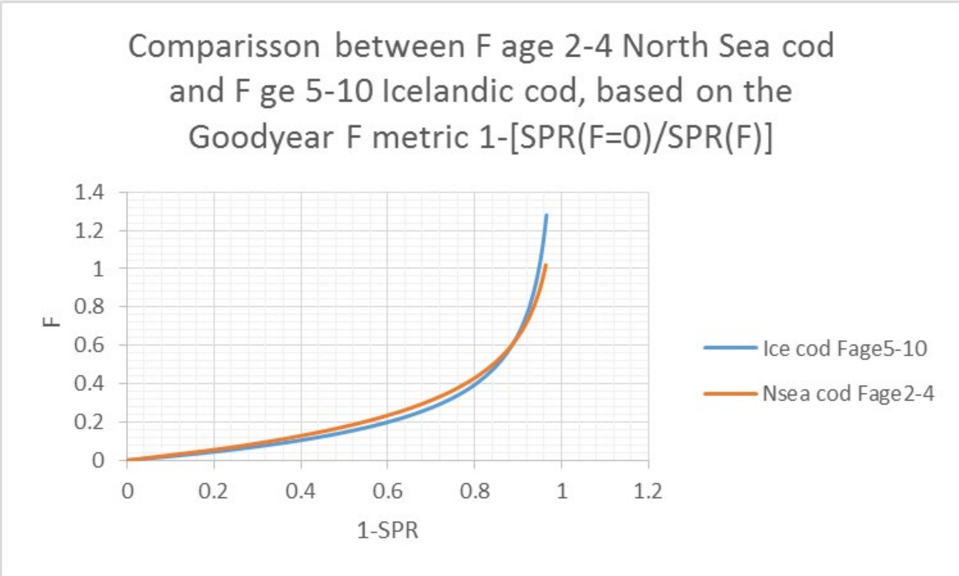


Figure 2.1.4. *Comparison of the relation between F in ICES “currency” and the F metric (1-SPR) between North Sea cod and cod at Iceland.*

Thus it seems, that the way the age groups used by ICES when defining F for each stocks are chosen, appropriately reflects the dynamics of the stock and the influence by the fisheries. Generally, they are chosen to cover the age groups constituting the bulk of the catch. Thus, there is no need to make corrections in Fs when comparing Fmsy across stocks which we will do in WP 7, except maybe for variation in natural mortality M.

2.2 WP2 Regime shifts, climate changes, genetic changes due to fishing, and suspected misreporting historically.

Regime shifts are difficult to identify. There are many definitions of what it is. For the present project regime shifts substantially changes the productivity of a stock for many years in a row. As the normal length of our time series is limited and natural variation is large, it is important to not segregate the time series into too many sub-time series. It is a question of striking a good balance.

Maybe mega trends of increases in pelagic stocks in the Northeast Atlantic could be used to indicate regime shifts – in a rough way. This could be looked more into.

Regime shifts for Baltic cod (parasites) and sprat (temperature increases and predator pressure), NEA cod (new feeding areas in the northern part of the Barents Sea due to temperature increase), and mackerel (new feeding areas due to temperature increase), should be considered.

A recent paper Clausen et al. (2017) showed that the productivity in terms of recruitment and individual fish growth have decreased in recent years for North Sea herring and led to a lower Fmsy. However, the paper did not consider the possibility that the observed regime shift could be due to the large increase in pelagic fish populations in the entire Northeast Atlantic, where a substantial reduction in zooplankton seems to be a results of intensive grassing from these pelagic stocks (Figure 2.2.1). Thus, the regime shift observed by Clausen *et al*. might be exactly what the present project is about, density dependent factors in fish population dynamics.

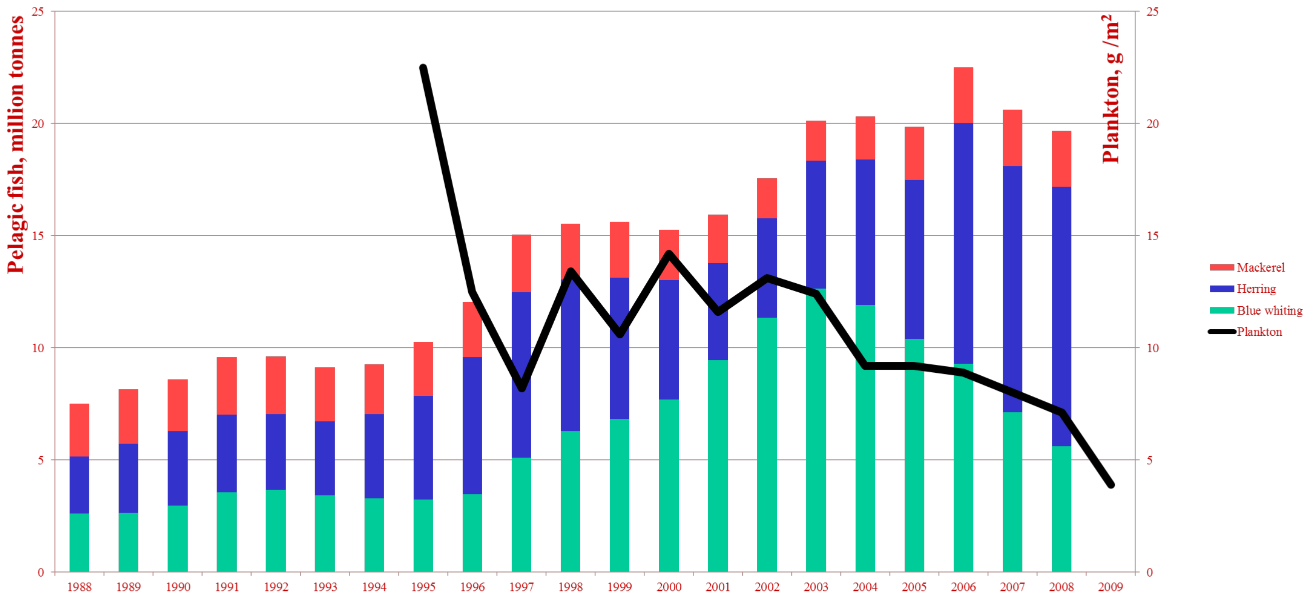


Fig. 2.2.1 Fluctuations in total biomass of pelagic fish and zooplankton in the Norwegian Sea. Loeng et al 2009.

Mega trends in the North east Atlantic were further investigated.

A notable feature is the periodic occurrence of herring (*Clupea harengus*) – now termed Norwegian Spring spawning herring – periods along the Norwegian coast (e.g. Boeck, 1871, Cushing, 1982). Periods of high abundance occurred in ca. 1600-1648, ca. 1700-1784, 1818-1870, 1896-1967 and since ca. 1987. There are similar periods of herring – belonging to locals stocks in the North Sea (Høglund, 1978) – at the Swedish coast along the Bohuslän (Swedish Kattegat coast) (Alheit and Hagen, 1997 and references therein) that are documented further back in time: 1307-1362, 1419-1474, 1556-1587, 1660-1689, 1748-1808, 1878-1906. After this 'open Skagerrak periods' have been identified: 1907-1920, 1943-1954, 1963-1965. Note that periods with Norwegian spring spawning herring seldom overlap periods of North Sea herring.

These herring periods have been linked to climate. Norwegian Spring spawning herring periods occur in warm temperatures (Toresen and Østvedt, 2000) and North Sea herring occur in cool temperatures (Alheit and Hagen, 1997). Temperature may just be one measure of a broader picture where the strength and location of dominating low- and high pressures in the North Atlantic differ between periods. Warm conditions occur when a strong low pressure is located near Iceland in winter and a strong high pressure close to the Azores, i.e. a positive NAO index, which causes strong south-westerly winds to dominate parts of the Norwegian Sea and the North Sea. Cool conditions occur when the low- and high pressure are of less magnitude (the NAO index is negative) and the westerlies are weaker.

It should be noted, however, that absent herring along the Norwegian or Swedish coast have been associated with not only low stock sizes but also with other factors, e.g., changes in migration routes. It is well known that the migration pattern of Norwegian Spring spawning changed markedly between 1950 and 2003 (Holst et al., 2004).

The causal relationship between climate change and the occurrence of herring periods is difficult to assess and temperature *per se* is unlikely to be the most important factor. It is more likely food or predation at some stage in the life cycle of herring. There is a very strong positive correlation between the stock size of offshore cod in Greenland (up to ca 1985) and the stock size of Norwegian Spring spawning herring, as well as with sea surface temperature.

The presence or absence of herring might affect other fish species. A well-known example is the 'Gadoid outburst' or 'Gadoid upsurge' in the North Sea in the 1960s and 1970s that occurred just after the decline of the North Sea herring stock. The outburst refers to the increase in many Gadoid stocks in the North Sea during this period. Cushing (1980) explored the effect of increased food and of reduced predation on Gadoid stocks in the North Sea. Considering the three main local populations of herring (Down, Dogger and Buchan/Shetland) and the timing and location in food for, and predation on, cod, haddock, whiting, Norway pout and sandeel, Cushing came to the conclusion that food might have been released by herring to postlarval cod and that I-group herring might have predated less on 0-group cod during the Gadoid outburst when herring were scarce. Cushing also proposed an alternative explanation that the Gadoid outburst was initiated by climatic factors and that this scenario also required a 'transfer of food from some source, for example the planktonic reserve'.

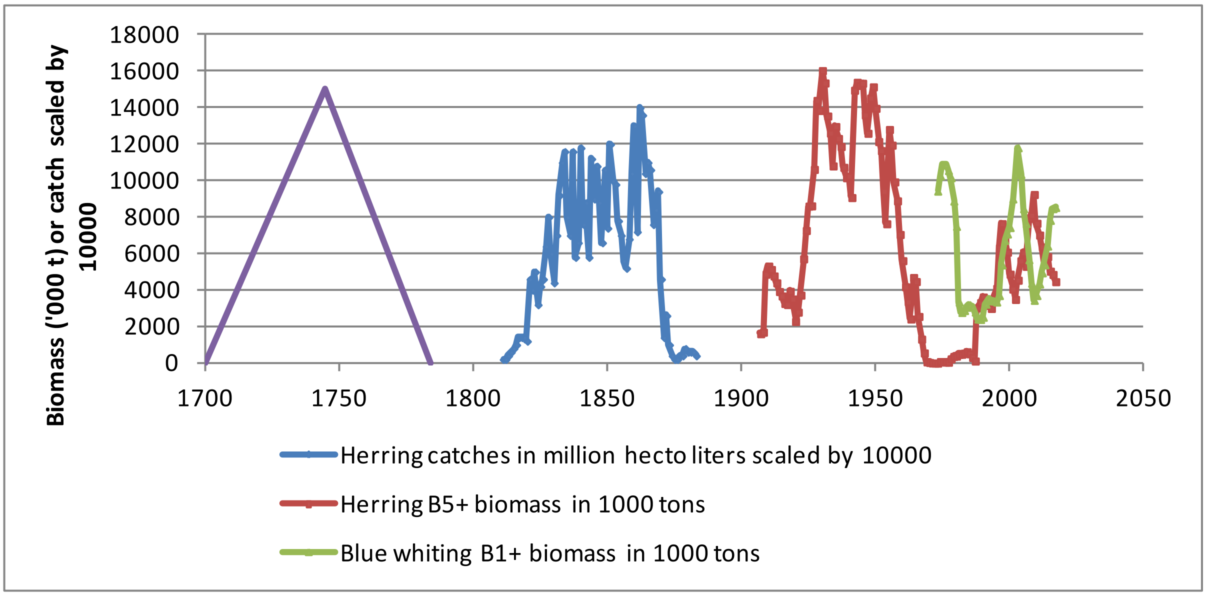


Figure 2.2.2 *Stock biomass of Norwegian spring spawning herring (age 5+) (Toresen and Østvedt, 2000, ICES 2017d) and blue whiting (age 1+) (ICES, 1984, ICES 2017d). The biomass of herring before 1900 is indicated by scaling the catches (Devold, 1963) by a constant so that the biomass matched the biomass after 1900. The herring period from 1700 to 1784 is also indicated.*

Temperature might not only affect pelagic fish species, such as herring, but also demersal fish species, such as cod. It is well known that cod recruitment of 'warm-water' cod stocks is negatively affected by high temperature whereas 'cold-water' cod stocks are positively affected (Planque and Frédou, 1999). Recruitment data for 5 warm-water cod stocks (North Sea, English Channel, Irish Sea, West of Scotland, Faroe Plateau) were collected from ICES working group reports (ICES, 2017a-c). Faroe Plateau cod is included as a 'warm-water' stock although it did not show any relationship with temperature in Planque and Frédou (1999). Recruitment was provided for age 1 for four of the stocks and for age 0 for Irish Sea cod, which was shifted by one year to show age 1 recruitment. A geometric mean was taken of all recruitment series at age 1, and shifted to age 0, and compared with sea surface temperature from the Faroes (although other time series of temperature could have been used as well). There was a strong negative relationship between temperature (at the Faroes) and the composite recruitment of the five cod stocks, especially when recruitment was shifted to age 0 (Figure 2.2.3). There were two other stocks available, Norwegian Coastal cod and cod in Kattegat. These series were too short for this analysis, but they followed well the tendency for the 5 stocks. As mentioned earlier, temperature *per se* may not be the causal factor but rather some indirect effect related to food or predation. It has been proposed that high temperature during winter may lower the fat content of sandeel, an important food for cod, because of an increased standard metabolism of sandeel during winter when they do not feed (Eliassen, 2013).

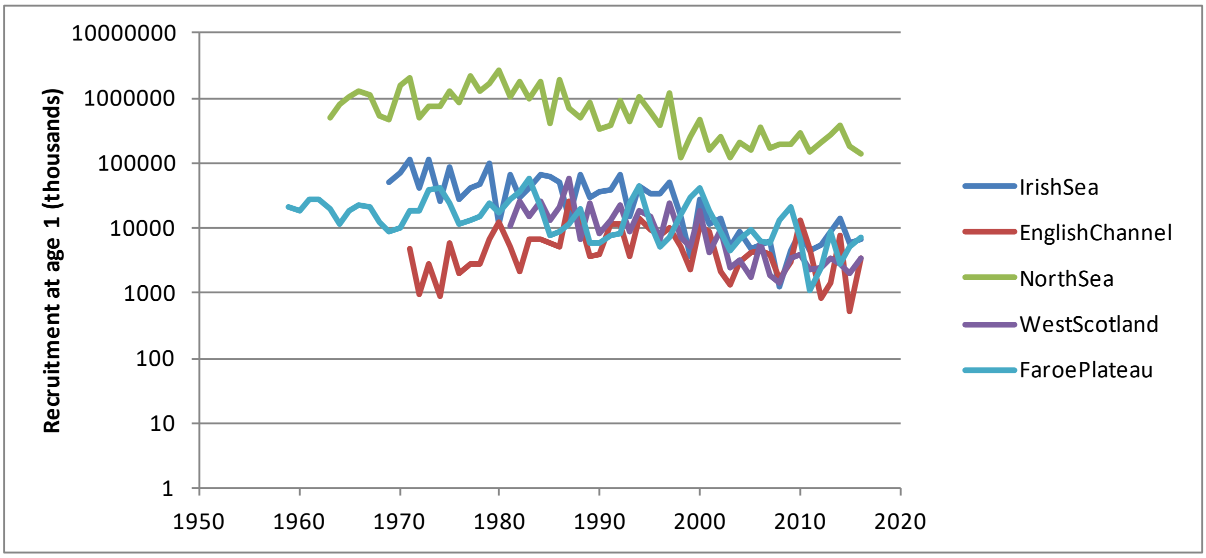


Figure 2.2.3 *Time series of the recruitment for 5 'warmwater' cod stocks.*

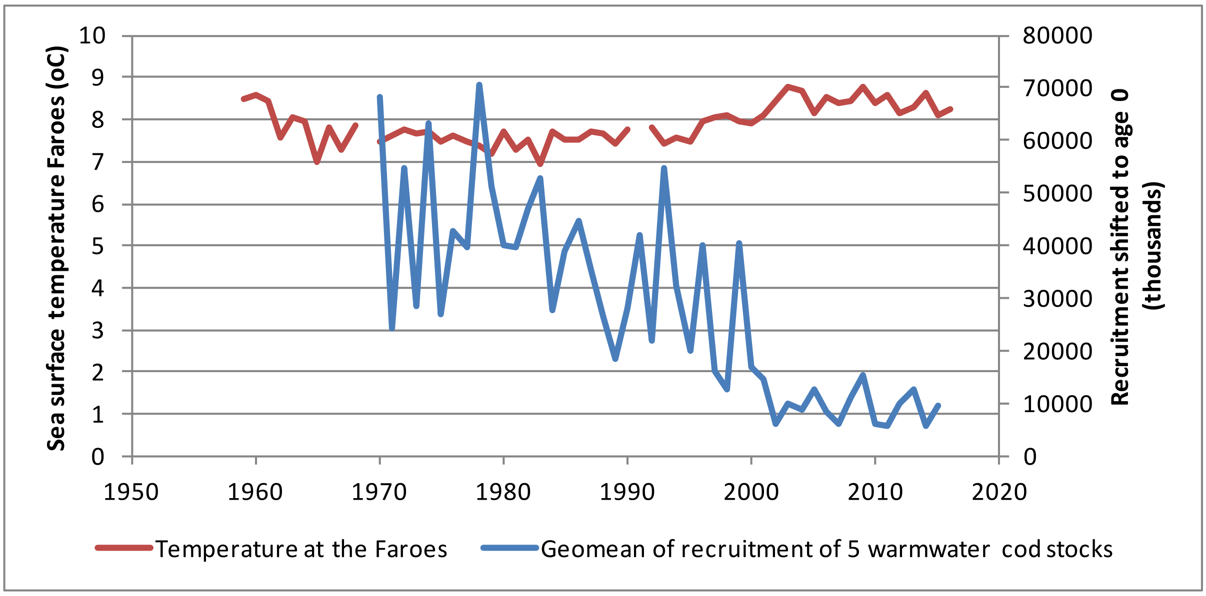


Figure 2.2.4 *Time series of recruitment, shifted to age 0, estimated as a geometric mean for 5 warmwater cod stocks (North Sea, English Channel, Irish Sea, West of Scotland, Faroe Plateau) and compared with sea surface temperature at the Faroes (whole year).*

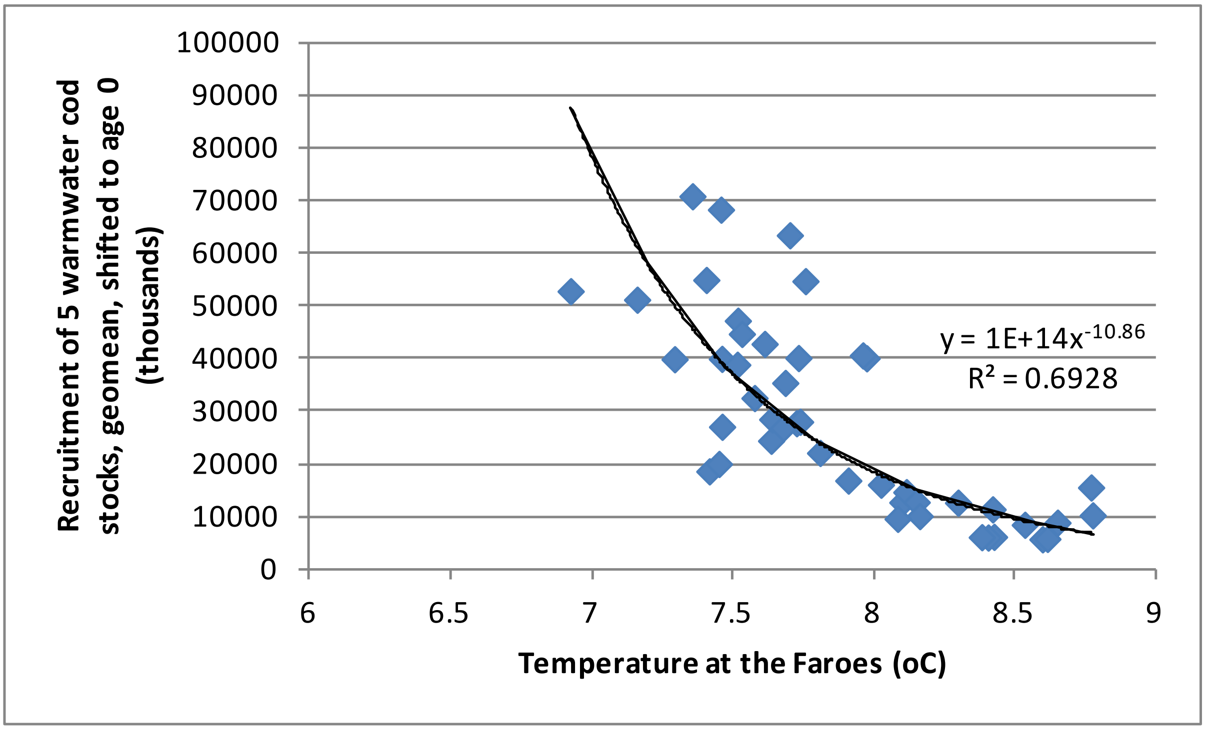


Figure 2.2.5 *Scatterplot of sea surface temperature (whole year) and recruitment for 5 warmwater cod stocks.*

The negative relationship between recruitment of 5 warm-water cod stocks and temperature (Figure 2.2.4, Figure 2.2.5) may seem convincing, but has the statistical drawback that there is a prominent autocorrelation in the two series. All the high recruitment points occur before year 2000 when the temperature was low and many of the low recruitment points occur after year 2000 when the temperature was high. Ideally, there should be several cycles of cold and warm periods in order to get a statistically reliable relationship.

The decline of the Norwegian spring spawning herring (Figure 2.2.2) and of North Sea herring in the 1960s led to the search for other abundant pelagic species to fish in the North Atlantic and the target became blue whiting (*Micromestistius poutassou*). The stock size of blue whiting is unknown before the 1970s, but there are indications that the stock was large in the mid-1970s (ICES, 1984, ICES, 2017d) (Figure 2.2.2, Figure 2.2.6).

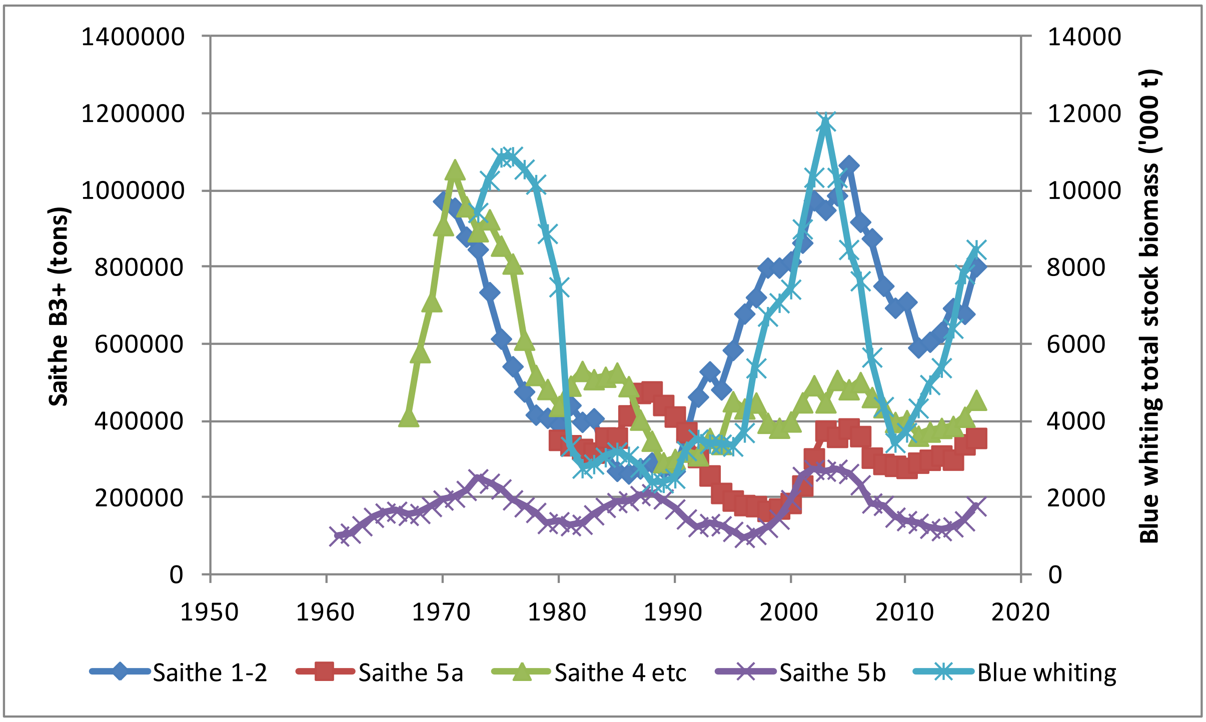


Figure 2.2.6 *Biomass of blue whiting compared with biomass of saithe stocks in the North Atlantic.*

There is a positive relationship between the biomass of blue whiting (ICES 2017d), and the biomass of most saithe stocks in the North Atlantic that also vary in the same way (ICES 2017a,b,e) (Figure 2.2.6). Even though the connection could be of a general sense, e.g. climate, in this case a simpler mechanism may be relevant, namely that blue whiting is an important food for saithe (at least in Faroese waters). Since blue whiting do not appear in saithe stomachs until age 3 or 4 years (the smaller saithe inhabit shallow waters where blue whiting are absent) this indicates that the recruitment variability of saithe may be regulated at age 3 or 4, although no firm conclusions can be drawn just from this piece of evidence.

A marked feature is the long-lasting nature of herring periods being absent or present, typically several decades. This type of variability is easy to cope with since it requires infrequent updates of Fmsy values. It is not known whether the same type of variability characterizes blue whiting, although a negative relationship between the biomass of Norwegian Spring spawning herring and blue whiting may be apparent in Figure 2.2.2. Since the current project focuses on short term Fmsy values that probably need to be updated every 5th year or so, this frequency of updates is much faster than changes in temperature regimes.

There seems to be one type of short term variability where the period is 7-10 years (Figure 2.2.7). This variability may be linked to the abundance of short-lived prey species such as sandeel (Figure 2.2.8) and capelin. This type of variability is included in the simulations determining Fmsy values that typically are based on periods that are more than 20 years long.

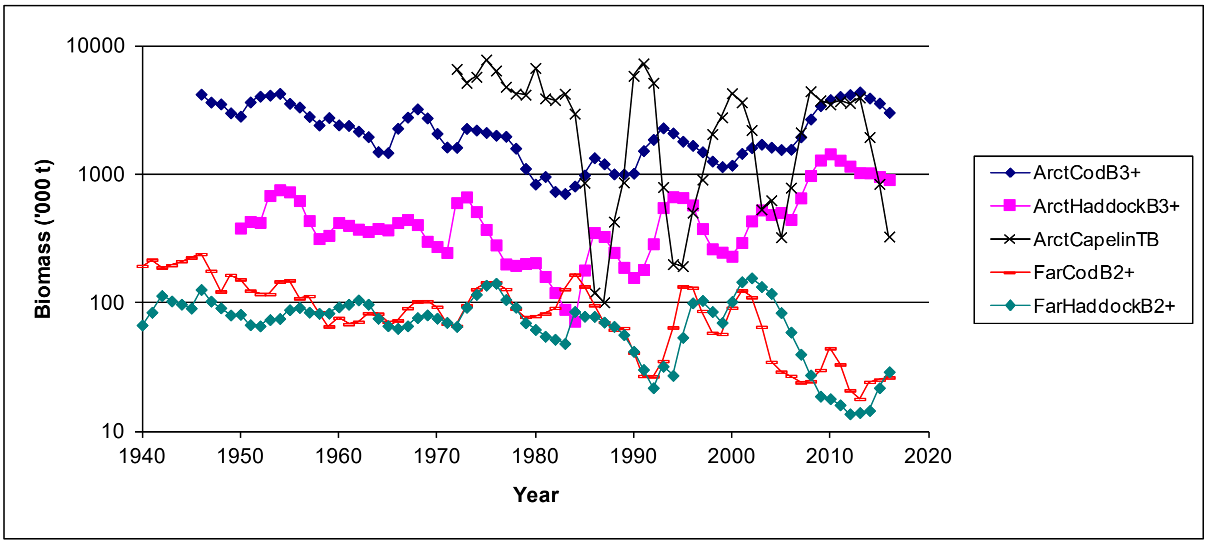


Figure 2.2.7 *Biomass of cod and haddock at the Faroes and in the Barents Sea as well as Arctic capelin.*

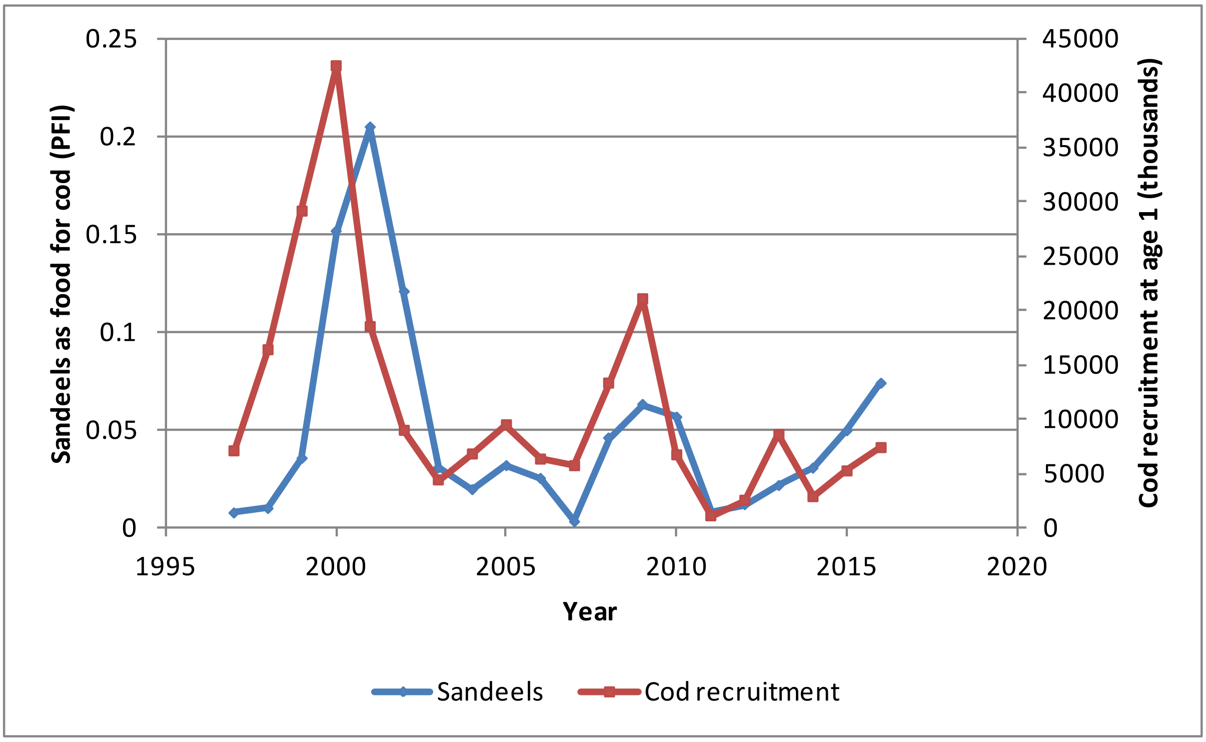
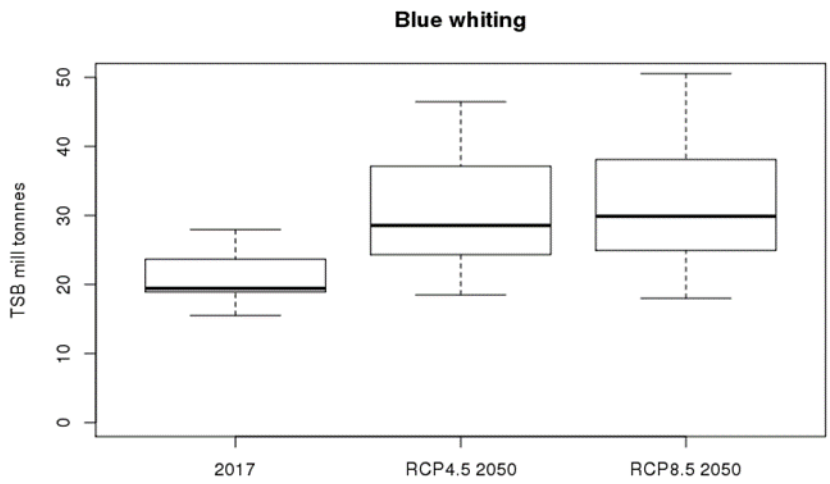
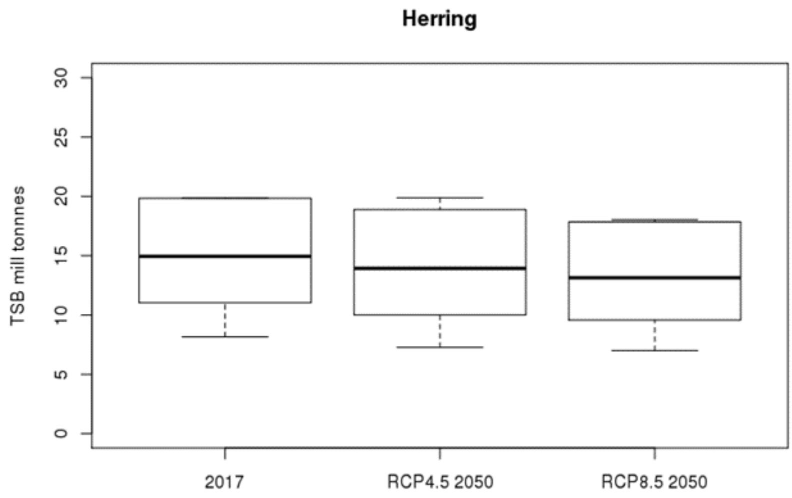


Figure 2.2.8 *Partial fulness index (PFI) of cod preying on sandeels (March and August pooled) on Faroe Plateau compared with the recruitment of Faroe Plateau cod. The correlation between sandeels and cod recruitment shifted to age 2 is 0.88.*

The periods selected for Fmsy determinations could be adapted to ecosystem dynamics, e.g. calculating Fmsy values for Norwegian Spring spawning herring for the last warm-water period (1981-2017) and not including the cooler period in the sixties-seventies, and this is exactly what has been done in practice. However, this exercise probably needs to be done on a case-by-case basis in order to balance presumed ecosystem states and the necessity to have long time series as a basis for reliable Fmsy determinations. In some cases, e.g. with Faroe Plateau cod, a shift to another regime in recruitment may not necessarily change the value of the Fmsy even though the maximum sustainable yield is changed (benchmark workshop, WKFAROE2017).

Climate changes in the Northeast Atlantic is of course a fundamental issue. How this will affect the Fmsy values for the various stocks and when is relevant for this project. A multi-year project called Climefish has just started. However, there were already some research presented at their first meeting and predictions made of future stock productivities of the three large pelagic stocks in the Northeast Atlantic (blue whiting, mackerel and NSSP herring). The figures below shows that for blue whiting and mackerel the forecasts are positive and for herring slightly negative.





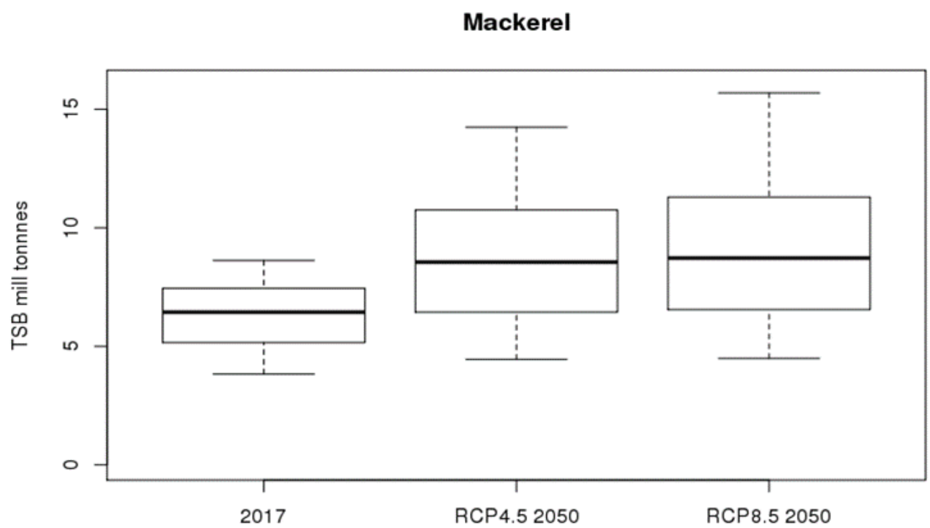


Figure 2.2.9 *Forecasts for 2050 for two climate scenario of the stock size of blue whiting, mackerel and NSSP herring in the North east Atlantic at current Fmsy fishing.*

The effects are not dramatic and indicates that including climatic changes in the present project, which aims of having updates of Fmsy values every about five years, is not of paramount importance.

2.3 WP3 Compile ecosystem and multispecies estimates of Fmsy

The task is to compile ecosystem and multispecies Fmsy from “published” work (also WG reports, Working Documents), including a short description of the model/assumptions used. It should refer to current situation in terms of balance between stocks.

Most relevant literature seems to be pre-2008, as most recent literature have focused more on improving the models than extracting results that can be used in management here and now. However, also relevant are the review in 2008 and 2012 by the ICES Multispecies WG and ICES advice 2012 and 2013 on Baltic and North Sea multispecies Fmsy.

The project group received a description of an extraction from the Nordic and Barents Seas Atlantis model (NoBa) (Hansen et al., 2016). Very kindly supplied by Cecilie Hansen Eide, IMR in March 2018. The model uses 57 species and functional groups to represent the ecosystems of the Nordic and Barents Seas. The model requires daily physical forcing, this is provided from a ROMS model (check ref) covering the area with a horizontal resolution of roughly 20 km. NoBa provides output in 4D, covering both time and space.

Multispecies Maximum Sustainable Yield (mMSY) has been calculated for 9 species (Table 2.3.1). This was done by applying historical/constant current fisheries pressure for all other stocks but the stock in question. The harvest pressure for the stock for which the mMSY was to be calculated was increased stepwise until the stock collapsed. This first step included numerous simulations for each stock, usually starting with an annual fisheries mortality of F=0.1, 0.2, 0.4, 0.8, for thereafter exploring which of these lead to the highest catch at the same time as avoiding the stock to collapse. From there, refinement of the fisheries mortality was performed, determining this within a 2-digit certainty.

Table 2.3.1. *Multispecies maximum sustainable yields for eight commercially important fish stocks, and in addition for the mesozooplankton (representing Calanus finmarchicus).*

Species	mMSY
Haddock	0.225
Saithe	0.065
Northeast atlantic cod	0.4
Beaked redfish	0.13
Golden redfish	0.15
Greenland halibut	0.1
Mackerel	0.245
Norwegian spring spawning herring	0.15
Mesozooplankton	6.5

The mMSY could not be calculated for Capelin, as this is a short-lived stock, which dies after spawning. Hence, calculating the mMSY, when the option is being fished or die, is challenging.

NoBa was initiated in the early 1980s, and is being run continuously from that period until present day, with the opportunity to do scenario modelling forward in time including the period until 2068. The mMSYs are calculated using 55 year runs, where the biomass and catches used for producing the mMSY are averaged over the last 5 years of the simulation.

NoBa has been compared with biomass and catch levels of the large commercial stocks, and is able to catch the patterns for the larger parts of the stocks. On a common basis, the most challenging is to catch the huge recruitment successes of herring, which roughly happen every 10^{th} year, and the 'boom and bust' behavior of capelin.

A sensitivity study has been performed with the model, identifying growth as the most important single life-history parameter, whereas the most influential component (ecosystem wise) was the zooplankton groups (Hansen-Eide et al., in prep.).

The present project will contact Hansen and her colleagues to find out what currency is used for F and to check which HCR was used in the calculations. If this can be sorted out and the reliability of the model documented then the results from this model seems very interesting for the current project or maybe more realistically, for the update of the Fmsy values five years or so from now.

The MSY analysis from the Vancouver on EwE key runs of:

- North Sea 1991-2013 run from WGSAM (Mackinson et al. (key run, anomalies removed).
- Baltic Sea 2004-2014 run from WGSAM (Bauer & Tomczak, (updated key run)).
- Iceland (Rebeiro & Stefansson).

Results were extracted for two run types:

1. "stationary system": target species abundance does not impact other species = SS run.
2. "full compensation": target species abundance affects other species = MS run.

FMSY estimates were extracted for each run type, and subsequently used for runs with all F by species at (1) FMSY_SS or (2) FMSY_MS. The results are shown in Table 2.3.2.

Table 2.3.2 *Results of EwE runs for the Baltic, Iceland and the North Sea. "Stationary system": target species abundance does not impact other species = SS run. "Full compensation": target species abundance affects other species = MS run.*

			SS-FMSY	**ES-FMSY**
Area	**Group**	**Year classes**	**Fmsy**	**Fmsy**
Baltic	AdCod_3	3+	0.17	0.50
Baltic	AdHer_2	2+	4.85	4.95
Baltic	AdSpr_2	2+	0.40	0.73
Iceland	Cod	4+	0.23	0.31
Iceland	Haddock	3+	0.73	0.65
North Sea	Cod	3+	0.83	0.83
North Sea	Haddock	2+	0.76	0.76
North Sea	Saithe	4+	0.63	0.63
North Sea	Hake		0.40	0.40

North Sea	Herring	2+	0.52	-
North Sea	Plaice		0.29	0.43
North Sea	Sole		0.36	0.36

Baltic herring Fmsy values seem extremely high and it is unclear what the reason is for that.

John Pope presented The Trade-Offs North Sea MODEL (T-ONS) from the MareFish project. The aim is to amalgamate as much advice as possible and put it on the desk top to consult how managers want to develop the fishery. It covers:

- Both species and fisheries interactions.
- Handles the main range of TAC species.
- Allows fishing to be changed in a realistic fashion.

It should show the important trade-offs, e.g.:

- Species Yield, Fleet Economics.
- Social implications.
- Ecosystem Effects.
- BUT most of all it MUST BE:-
    - Transportable, Easy to understand and Responsive.

T-ONS is based upon Excel. It uses approximations to more complex multi-species models.

It is based on SMS model and some simple fleet models and the link is via a Jacobian matrix with relative Fs so that ϕ is F/F(status quo) and the formula below:

$$\frac{\partial yield(i)}{\partial \Phi_j}$$

It uses a quadratic approximation of the local yield surface. The user's interface looks like shown in Figure 2.3.1.

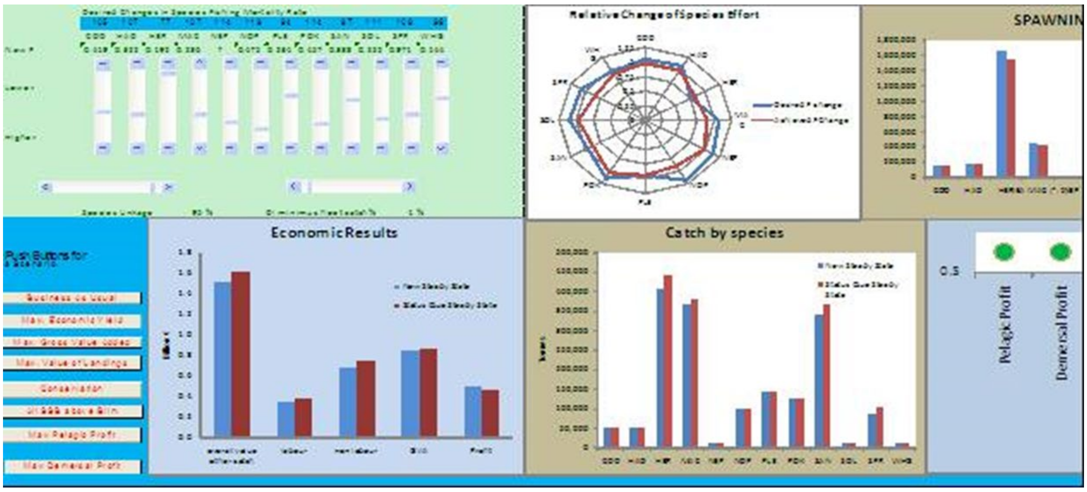


Figure 2.3.1 *User interface of T-ONS model – a multispecies and –fleet model of the North Sea.*

Runs of the model suggested that yield could be increased by increases of the current F to the maximum allowed in the model – a 25% increase.

From a more theoretical point of view John Pope presented a very simple model (CSM) with:

- 12 "species" with different L_∞ (10 to 130 cm).
- They are recruited, eat, grow, reproduce, get eaten, get taken by fisheries, and die of "other causes".
- All these things depend on length, and RATES of many of these things depend on L_∞.
- Rates etc. are linked to L_∞ by the Charnov "Life History Invariants").

The dynamics resulting from such a model shows some very interesting general features (Figure 2.3.2). It can be seen that the overall yield is maximized at a very high F of around 2.0. This is due to fishing out the predators and to the yield of fish with Linf less than 30cm. It also shows how M2 by size varies by F (lower right hand panel). <u>Maybe this type of analysis can be useful in the present project to make a default density dependence relationship between natural mortality and F for non-cannibalistic stocks?</u>

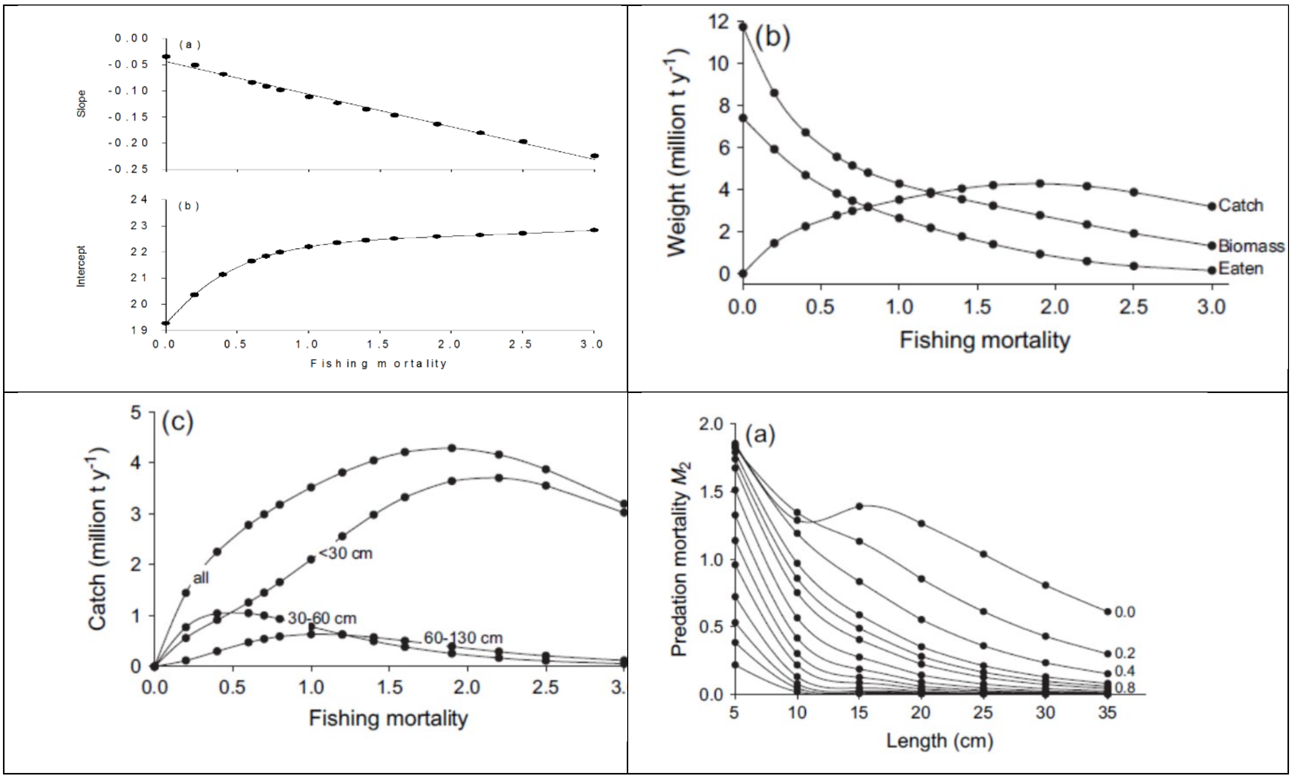


Figure 2.3.2 *Results of the CSM model.*

2.4 WP4 Surplus production model estimates of Fmsy

In our June report we presented a suggestion for criteria for leaving out of a stock from the SPM analysis, where it was obvious that an SPM would not work. These criteria were:

1. Stock unit not well defined, e.g. cod WScot.
2. Catch data far from reliable.
3. Stock that have demonstrated large changes in carrying capacity.
4. Stocks with one or a few very large year classes in its historical time series are not suitable because the historical stock development will be driven by these year classes and mask the density dependent dynamics of the stock, e.g. W horse mackerel, maybe North Sea haddock and NSSP herring).
5. Stocks with suddenly strong parasites or diseases events or starvation – or at least these periods should be left out, e.g. cod Baltic SD2532.
6. Stocks with little dynamic range in catch and SSB.

7. Stocks with short time series.

8. Stocks with large changes in exploitation pattern over the time span considered, e.g. NSSP herring.

9. Stocks which gives very different temporal stock biomass development using surplus production models (like by Froese et al 2016) than the ICES estimated temporal biomass development.

10. Stock like cod WScot, where stock development obviously driven by some (unknown) environmental factors that goes clear against normal population regulation mechanisms. For cod WScot the stock is increasing in spite of increasing catches over time.

11. Stocks where predation pressure has varied strongly over time, e.g. Baltic sprat due to large changes in the cod SD2523 stock. Maybe a shorter time series can be used.

We stated that "The list of criteria to be used for selection of stocks for running SPMs should be finalized before the next meeting." No corrections have been identified as needed, and therefore these criteria stand.

At this meeting the criteria used by RAM Legacy database was listed. They are:

a) number observed SP points > 5
b) more positive than negative SP points in middle quadrants
c) sum of SP points in middle quadrants > 0
d) ERMSY > 0.005
e) 0.9 > ERMSY
f) BMSY > 0.05 * Bmax
g) 2 * Bmax > BMSY
h) The production at BMSY from the assessment > 0
i) linear fit worse than SP fit,

…where ER is exploitation rate and thus comparable with F. Points e) to g) are not relevant for ICES stocks because there are no Bmsy defined for these. These Ram Legacy database points are more technical than the June list, but overlapping. For instance point a) is similar to point 7. The points 1-11 filtering means that RAM Legacy database filtering only had effect on a few stocks (Table 2.4.1).

Table 2.4.1 *RAM database filtering of stocks that passed the 1-11 point filter of the present project.*

	ICES Fmsy	Froese et al. Fmsy	Froese et al.	Schaefer Fmsy	Thorson tax Fmsy	Thorson pooled Fmsy		RAM db

			No of years		Model 5	Model 7	Model 8		No of years
Cod Irish Sea	0.37	0.95	48						8
Cod in divisions 7.e–k (western English Channel and southern Celtic Seas)	0.35	0.56	45						
Cod Western Baltic Sea	0.26	0.62	46						21
Haddock Rockall	0.20	0.31	25						24
Haddock Irish Sea	0.27	0.41	21						
Herring W Scotland and W Ireland	0.16	0.22	59		0.09				58
Herring N. Irish Sea	0.26	0.43	55						54
Saithe North Sea etc.	0.36	0.54	39						48

F_{MSY} reference points based on the RAM Legacy Stock Assessment Database

In the RAM database set-up all stocks were exposed to 18 different SP models. A full account of the analysis is presented in Appendix 3.

Because we focus on revising current reference points the "Bmsy free" are the relevant runs for the present project.

The models with TB (total biomass) are clearly better than those based on SSB because SSB is only a part of the stock and the SP models in RAM database assumes absolute values of biomass, i.e. no catchability is estimated, but assumed to be 1. TB is also better than VB (catch/F) because the F values (which is from ICES assessments) are typically about a factor of 2 larger than the SP relevant F, which is a weighted average F over all ages (weights being biomass of each age group). The metric VB therefore also underestimate exploitable biomass (by a factor of about two). Furthermore, the diagnostics from the runs also confirmed that TB is best (Table 2.4.2).

Table 2.4.2 *Diagnostic from the RAM db runs. A is number of stocks passing the filter process. B Correlation coefficient between predicted and observed values. C mean delta AICc values where AICc is set to zero for the best model of all 18 models. A low values is indicating a good model. In B and C only stocks passing the test for all models are included.*

A.

	B_{MSY} free	
model	n	% passed
SSB ; Schaefer	71	80%
SSB ; Fox	71	69%
SSB ; P-T (Taxon)	71	77%
SSB ; P-T (Pooled)	71	77%
TB ; Schaefer	75	85%
TB ; Fox	75	76%
TB ; P-T (Taxon)	75	83%
TB ; P-T (Pooled)	75	83%
VB ; Schaefer	69	86%
VB ; Fox	69	71%
VB ; P-T (Taxon)	69	77%
VB ; P-T (Pooled)	69	86%

B.

	B_{MSY} free	
model	n	mean *r*
SSB ; Schaefer	34	0.22
SSB ; Fox	34	0.23
SSB ; P-T (Taxon)	34	0.23
SSB ; P-T (Pooled)	34	0.22
TB ; Schaefer	34	0.30
TB ; Fox	34	0.31
TB ; P-T (Taxon)	34	0.31
TB ; P-T (Pooled)	34	0.31
VB ; Schaefer	34	0.25
VB ; Fox	34	0.27
VB ; P-T (Taxon)	34	0.26
VB ; P-T (Pooled)	34	0.26

C.

model	B_{MSY} free n	mean ΔAICc
SSB ; Schaefer	34	6.4
SSB ; Fox	34	4.5
SSB ; P-T (Taxon)	34	6.1
SSB ; P-T (Pooled)	34	5.9
TB ; Schaefer	34	2.4
TB ; Fox	34	2.6
TB ; P-T (Taxon)	34	2.4
TB ; P-T (Pooled)	34	2.4
VB ; Schaefer	34	3.7
VB ; Fox	34	2.9
VB ; P-T (Taxon)	34	3.6
VB ; P-T (Pooled)	34	3.4

In the final selection of models the TB with Fox SP setting were also filtered out, because it performed slightly worse than the other three.

The final set of Fmsy values in the ICES currency is given in Table 2.4.3.

Table 2.4.3 *RAM database Fmsy in ICES currency. "No years" is the length of the time series used. "Thorson tax" is the production curve shape from Thorson et al 2012 meta-analysis for the relevant taxonomic group and "Thorson pooled" is from the same source, but all taxon pooled. "Schaefer" is the traditional symmetrical production curve. Missing values represent filtered out runs due to the RAM database criteria.*

stock	Schaefer Model 5	Thorson tax Model 7	Thorson pooled Model 8	No years
Blue Whiting Northeast Atlantic	0.27	0.27	0.25	33
Cod Celtic Sea	0.51	0.51	0.46	44
cod Faroe Plateau	0.46	0.46	0.45	56
cod Iceland	0.50	0.49	0.50	60
cod IIIa (west) and IV-VIId	0.78	0.78	0.74	52
cod Northeast Arctic	0.48	0.49	0.48	69
Cod Western Baltic Sea				21
Haddock Faroe Plateau	0.30	0.30	0.30	58

Haddock Iceland	0.43	0.43	0.43	36
Haddock Irish Sea				
Haddock Northeast Arctic	0.36	0.36	0.35	65
Haddock North Sea and IIIa-VIa	0.56	0.56	0.61	42
Haddock Rockall Bank				24
Haddock ICES VIIb-k	0.86	0.86	0.88	22
Hake Northeast Atlantic North	0.41	0.41	0.38	37
Hake Northeast Atlantic South	0.51	0.51	0.50	33
Herring ICES 22-24-IIIa	0.31	0.26	0.29	24
Herring Subdivisions 25-29 and 32	0.17	0.16	0.17	41
Herring Iceland (Summer spawners)	0.29	0.31	0.30	27
Herring Northern Irish Sea				54
Herring Norwegian SSP	0.18	0.18	0.18	26
Herring IIIa, VIId and North Sea	0.26	0.28	0.27	68
Herring ICES 28	0.51	0.49	0.50	38
Herring ICES VIIa-g-h-j	0.45	0.50	0.47	57
Herring ICES VIa-VIIb-VIIc	0.09			58
Mackerel ICES Northeast Atlantic	0.32	0.34	0.32	33
European Plaice ICES VIId	0.27	0.23	0.25	35
European Plaice North Sea	0.38	0.36	0.37	58
Saithe Faroe Plateau	0.36	0.36	0.35	54
Saithe Iceland Grounds	0.30	0.30	0.29	35
Saithe Northeast Arctic	0.32	0.32	0.31	55
Saithe ICES IIIa, VI and North Sea				48
sole Celtic Sea	0.44	0.51	0.47	44
Sole Irish Sea	0.27	0.23	0.26	45
sole 22-24-IIIa	0.28	0.26	0.27	31
sole North Sea	0.41	0.45	0.42	58
sole ICES VIId	0.69	0.80	0.73	33
sole Western English Channel	0.21	0.18	0.20	46
sole VIIh-k				
sole VIIIab	0.38	0.34	0.37	31
Sprat ICES Baltic Areas 22-32	0.29	0.30	0.29	41
Atlantic menhaden Atlantic	0.76	0.74	0.75	61
Summer flounder Mid-Atlantic Coast	1.08	1.12	1.10	32

Fmsy calculations based on Froese et al (2016)

Here it should be mentioned that the SP models have a small twist by including a specific S-R model at low stocks sizes in order not to overestimate the recovery potential at low stock sizes. Whether this gives a bias in the estimates of Fmsy is not clear, but by comparison with RAM db and SPiCT Fmsy calculations this does not seem to be the case.

SPiCT

SPiCT is an R based program, a new and up-to-date system, which can do what we need for the MSY project.

There is a user's guide https://github.com/mawp/spict/blob/master/spict/vignettes/vignette.pdf .

The web page is https://www.stockassessment.org/login.php.

It was used at the ICES WKMSYKAT in spring 2017 on some about 30 SAM stock assessments, but using the basic data (catch and survey data) rather than the output from the SAM model.

It showed that F/Fmsy is better estimated than F and Fmsy separately. This fits well with what we intend to do in the current project, use F/Fmsy.

Compared to ASPIC, SPiCT account for noise in the catch data and for process error. Furthermore, ASPIC does not produce confidence intervals on all parameters estimated (though on most) while SPiCT produce it on all.

It was discussed which biomass metric is best to use in SPMs. SSB and sometimes also TSB is readily available from ICES Summary tables. However, alternative ones could be calculated quite easily from WEST and stock number at age data available in ICES assessment WG reports. Also catch/F, which in principle is CPUE, could be considered. So we have at least 4 alternatives:

1. SSB.
2. TSB (not always available but can be calculated easily from WEST and stock-number-at-age table.
3. Exploitable biomass calculated from WEST and stock-number-at-age table.
4. Catch/F.

All should be very correlated with each other, but in case F varies a lot over time TSB, Exploitable Biomass and catch/F might be better to use than SSB. Catch/F might be the best, because it is closely related to exploitable biomass and simple to obtain for the entire time series. To calculate exploitable biomass from WEST and stock-number-at-age table might not be possible for the entire time series, because WEST is often constant by year in the early part of the time series and thus not including what we specifically what to include (directly or indirectly) in the current project, namely density dependent effects. Furthermore, TSB includes fully the young ages which might not be fully recruited to the fishery and therefore probably should not be part of the exploitable biomass.

As stated above F in the ICES currency is different from F in the SP currency. The biomass weighted mean F over all ages are much more similar to the SP F currency. However, SPiCT is estimating a catchability parameters so as long as F in the ICES currency is proportional to the SP F, SPiCT should work fine.

A substantial amount of special analysis with SPiCT was presented.

Baltic stocks

Stocks with accepted analytical estimates of biomass and fishing mortality were considered:

- Herring in 20-24
- Herring in GoR
- Herring in Central Baltic (CBH)
- Herring in 30-31
- Sprat 22-32
- Cod 22-24

For sprat & CBH two options were used:

i. standard approach
ii. approach in which cod was treated as additional „fleet" and biomass of sprat & herring consumed by cod was added to the catches.

SPiCT was fitted to catches and analytical estimates of biomass (treated as survey indices, observed variable). For biomass, exploited biomass was taken, defined as

explB=Catch/F,

where F was average F-at-age weighted by biomass of age groups. Analytically derived exploited biomass is considered to represent absolute estimates, thus „survey" catchability was assumed close to 1. This was realized by assuming strong prior on q in SPiCT:

```
input$priors$logq<-c(log(1),sd,1),      sd=0.2
```

Two options were considered in relation to n, n fitted (Pella & Tomlinson model) and n=2 (Schaefer model). In addition, possible change of stock productivity was considered (e.g. regime shift in the Baltic, end of 1980s). Consequently, for most stocks data series were separated into two parts (e.g. before 1990 and from 1990 onwards) and both Schaefer and Pella & Tomlinson models were fitted to both series. Thus, in total 6 models were fitted for most stocks.

Selection of appropriate option from the models fitted for each stocks was done considering e.g.:

- trends in residuals (may suggest need for separation of data series)
- confidence intervals for estimated n (or Fmsy)
- value of objective function (negative log likelihood)
- diagnostics (especially autocorrelation in residuals, retrospective patterns, deviations from normality)
- MSY realistic ? comparison with historical catches
- Comparison of parameters determined for separated series

In all cases as best option seem runs with n=2 and data constrained to recent period (after separation year). When n was fitted, its CI were usually very wide, and contained 2; when CI for n were narrow, results were usually similar to results with n assumed at 2. Fits with all years included, usually showed some pattern in survey (biomass) and/or catch residuals, e.g. positive and negative blocks, suggesting change of productivity within analysed period.

The results are shown in Table 2.4.4. It can be seen that generally the model performances are rather poor. This is most likely due to short time series. Short time series are needed due to large changes over time in cod predation pressure on herring and sprat. For Cod 22-24 the short time series is due to a change in stock definition and a quite short year span in the new assessment. Here it would be interesting to explore a longer time series, maybe using old assessments in combination with the new one. This should be possible as there are many years of overlap in the two time series.

Table 2.4.4 *Results of SPiCT runs. The column "Fmsy-recalc" is the Fmsy in the ICES currency. The row with red text "M2 in" means that cod predation is taken as catch and thus the MSY is both commercial catch and amount eaten by cod.*

							for selected option						**for all**	**for n fitted**	
stock	ICES Fmsy	Fpa	avCatch	ages	selection	separ	Fmsy	MSY	ratioF weigh /Fbar	Fmsy-recalc	retro */	diagnostics	remarks for all	n fitted, Conf.Int	remarks
her20-24	**0.32**	0.45	95.2	3,6	**n=2, 2004+**	2004, lower R	**0.19**	**120**	**0.84**	**0.23**	acceptable	ok, no problems	trends in surv resids, +/-, separation justified	n=10.8, very wide CI, 2-43 !	n fitted - unrealistic results
					n=2, all	all	**0.20**	**105**					all data & n =2: similar results (0.2 & 105),good retro		
herGoR	**0.32**	0.63	25.8	3,7	**n=2, 1990+**	1990	**0.59**	**40.7**	**0.68**	**0.87**	very good	ok, no problems	dome shaped catch resids, some trends in surv, -/+, separation justified	all n=14, wide CI; 90+,n= 1, wide CI	
her30-31	**0.21**	0.23	60.6	3,7	**n=2, 1990+**	1990, higher R	**0.10**	**87.5**	**0.90**	**0.11**	poor	still trends in resids, separation in ca 1995 ?	negative/positive resids in surv	2.5 & 1.64 for all & 90+, very wide CI	low difference between n fitted and n=2, low efefct on Fmsy & MSY
herCB	**0.22**	0.41	202	3,6	**n=2, 1990+, M2 in**	1990, M2 from cod, R	**0.23**	**163**			quite good	ok, no problems	blocs of resids in survey, first part	0.47 & 0.44, not wide for all	unrealistic Fmsy for all (0.02), very high K, for 90+ similar F & MSY for n fit & n=2
herCB	**0.22**	0.41	202	3,6	**n=2, 1990+, no M2 in**	1990, M2 from cod, R	**0.23**	**163**	**0.72**	**0.32**		very similar to above ? To check			
spr22-32	**0.26**	0.32	237	3,5	**n=2, 1990+, M2 in**	1990, M2 from cod, R	**0.35**	**550**			good	better diagnostics than for all,	blocs of resids in C, smaller in survey, autocorrelation, no normality	1.6 & 1.2, CI narrow but with 2	no large differenc between Fmsy for all and 1990+, very similar MSY,
spr22-32	**0.26**	0.32	237	3,5	**n=2, 1990+, no M2 in**	1990, M2 from cod, R	**0.27**	**357**	**0.64**	**0.42**	moderate	better diagnostics than for all,	blocs of resids in survey & catch, poor doiagnostics	5.8 & 2.47, CI wide	
cod22-24	**0.26**	0.74	23	3,5	**n=2, 2005+**	2005, lower R	**0.54**	**20.2**	**0.80**	**0.68**	poor	ok, lag 2 in surv resids	trends in catch resids, +/-	n=0.8, 0.2-3	when n fitted: very wide CL for Fmsy , MSY>2*aVCatch, Bmsy unrealistic,
															pattern in residuals when all data, suggests change of productivity, unrealistic estim of K
											***/ looking at retro mind the scale (not from 0) , scatered results are not always very scatered !!!**				

Mackerel, blue whiting and North Sea cod, herring and plaice

Here SSB and catch/F were used in SPiCT runs. Detailed results are listed in the Dropbox folder Dropbox\ECOFmsy\Meetings\Rhode Island March 2018\Meeting documents\WP4. The summary results are presented in Table 2.4.5, based on selections criteria of the various runs as given above.

Table 2.4.5 *Fmsy values for various stocks. Displayed are the Fmsy values adviced by ICES, calculated by ICES without precautionary measures, and calculated by SPiCT when using the full time series available*

	ICES advice Fmsy	**ICES Fmsy unprecautionary**	**SPiCT Fmsy, plus 95% C.I.**
North Sea cod	0.31	0.31	0.63[ad] (0.45-1.36)
North Sea plaice	0.21	0.21	0.45[ae] (0.17-1.20)
North Sea herring	0.33	0.33	0.46[bf] (0.32-0.67)
Atlantic mackerel	0.21	0.23	0.32[bf] (0.12-0.82)
Blue whiting	0.32	0.42	0.50[c] (0.16-1.72)

[a] F used as effort index, no biomass index used.
[b] SSB used as biomass index.
[c] Catch/F used as biomass index.
[c] Not corrected for regime shift.
[d] Not corrected for abnormal recruitment in 1980s.
[e] Not corrected for misreporting.

Truncating the time series of a stock may give better information on the current state of the stock, which is useful if it is expected that the stock has experienced some inherent change in, e.g., its recruitment, mortality, and/or environment. However, surplus production models generally give more accurate results with longer time series, and truncating the time series may therefore also be detrimental to the results. To illustrate this, time series for calculating Fmsy have been truncated for a number of stocks. The results are displayed below.

North Sea herring

Data on herring SSB and landings were taken from the 2018 ICES benchmark. These data were fitted to the SPiCT surplus production model, with SSB as the biomass index and landings as the catch index. Model runs were performed with a progressively later starting year, starting with 1994 and ending at 2012. Fmsy values were converted to ICES currency. The results are given in Table 2.4.6 and Figure 2.4.1.

Table 1.4.6 *Fmsy of North Sea herring, as well as its lower and upper limit, depending on the start year of the time series. Fmsy values are converted from their SPiCT values to ICES currency.*

Start year	Fmsy	Fmsy lower limit	Fmsy upper limit
1994	0.589	0.132	2.622
1995	0.380	0.117	1.236
1996	0.206	0.148	0.292
1997	0.204	0.145	0.295
1998	0.199	0.138	0.300
1999	0.196	0.136	0.302

2000	0.195	0.130	0.315
2001	0.180	0.131	0.247
2002	0.173	0.121	0.245
2003	0.173	0.129	0.232
2004	0.177	0.155	0.204
2005	0.171	0.115	0.253
2006	0.180	0.124	0.262
2007	0.241	0.139	0.416
2008	0.258	0.074	0.905
2009	0.255	0.043	1.518
2010	0.361	0.033	4.003

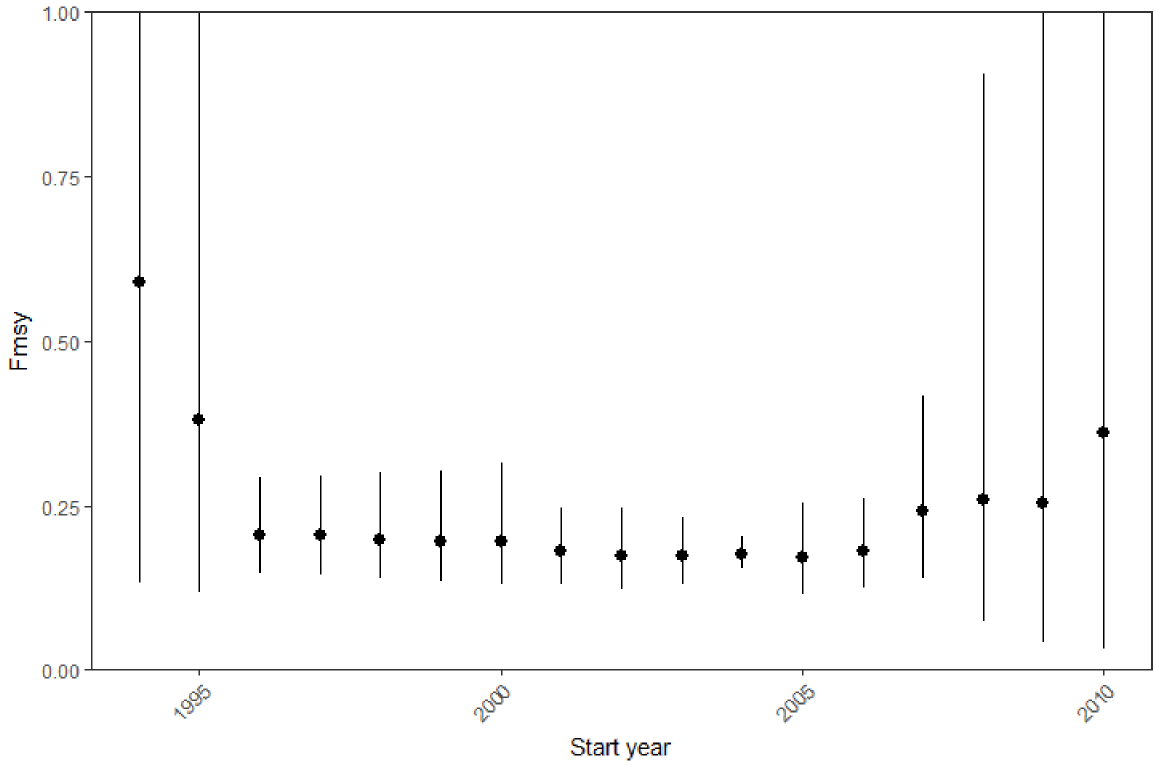


Figure 2.4.1 *North Sea herring Fmsy as calculated by SPiCT, depending on the start year of the time series. The black lines around the points indicate the lower and upper limit of the 95% confidence interval.*

Misreporting

Misreporting is a prevalent problem in exploitation time series. Because ICES relies mainly on recent data to calculate its advice, misreporting in older parts of stock time series is not always corrected.

Atlantic mackerel

There has been significant misreporting in the Atlantic mackerel fishery since at least the 1980s up until 2005. During WGWIDE 2013, Miller & Sparrevohn constructed a corrected catch and biomass time series based on estimated levels of misreporting. Fitting SPiCT to the corrected catch and corrected SSB as the biomass index resulted in an Fmsy in ICES currency of 0.23 (95% C.I. 0.16-0.33). However, a retrospective analysis showed that the reference points were highly sensitive to the last datapoint (Figure 2.4.2). Removing this last data point from the run results in a Fmsy in ICES currency of 0.24 (95% C.I. 0.18-0.35).

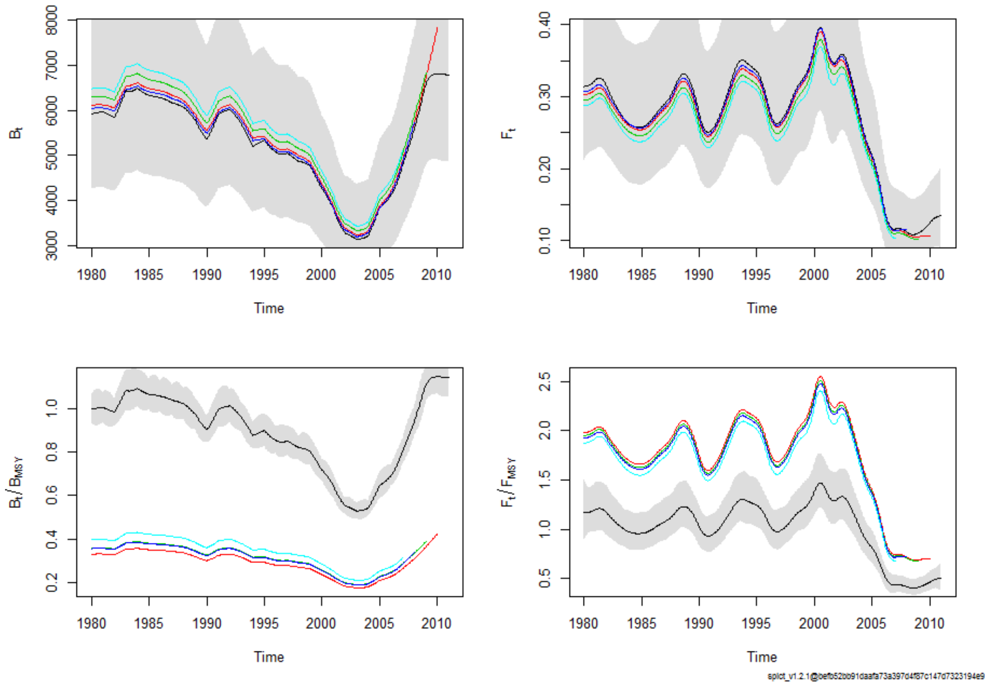


Figure 1.4.2 *Retrospective analysis of Atlantic mackerel time series, using catch and SSB corrected for misreporting. Removing the last point of the timeseries clearly results in different reference points for Fmsy and Bmsy.*

North Sea herring

Misreporting expected to have taken place between 1977 and 1982, during the closure of the North Sea herring fishery. There is evidence that a large number of the reported sprat landings actually consisted of herring (Figure 2.4.3). There are two ways to correct for the misreporting of herring during 1977-1982. One is to simply exclude these years from the time series. The other is to recalculate the expected catches of herring, assuming that the ratio of IBTS age CPUE to catch numbers-at-age is relatively constant.

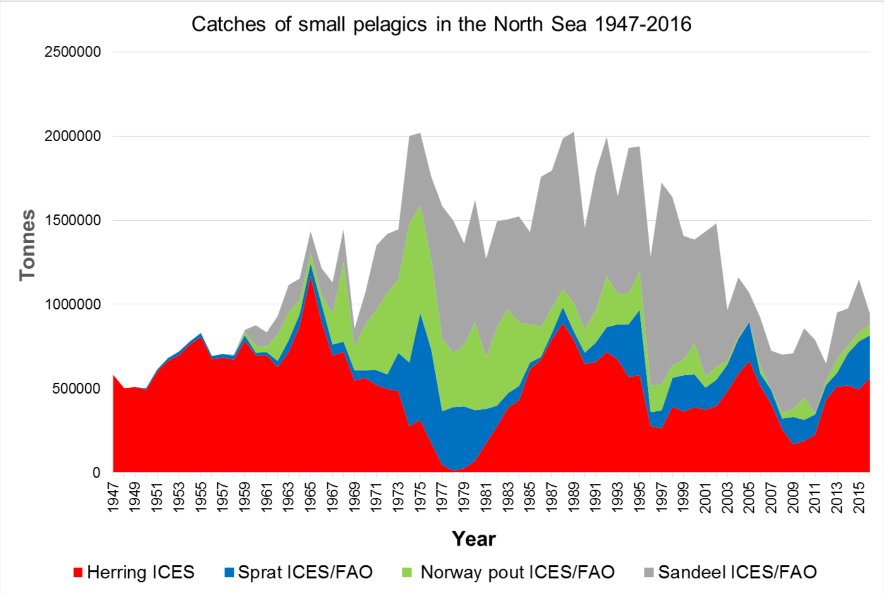


Figure 2.4.3 *Reported catches of herring, sprat, Norway pout, and sandeel in the North Sea. Note the reported catches of sprat during the closure of the herring fishery in 1977-1982, which decrease greatly after the herring fishery is opened again.*

Excluding the years 1977-1982 from the time series slightly reduces the Fmsy predicted by SPiCT, when compared to Table 2.4.5. With the years removed, Fmsy in ICES currency is then predicted to be 0.38 (95% C.I. 0.26-0.56), as opposed to the original of 0.46 (95% C.I. 0.32-0.67). Furthermore, the autocorrelation among the catch residuals is no longer significant (Appendix 4).

Alternatively, the herring catch data was corrected for misreporting by using IBTS indices together with catch data from 1982-1984. For this, it was assumed that, for each age group, there is a relatively constant ratio of catch numbers to IBTS CPUE. For each age group, this ratio for 1982-1984 was multiplied with IBTS CPUE of the years 1977-1981 to give estimated catch numbers of the respective age group for the respective year. Multiplying catch numbers with data on weight-at-age in the catch then gives the estimated corrected catch in tonnes (Table 2.4.7). Running SPiCT with this catch data, and SSB as biomass index, results in an Fmsy in ICES currency of 0.39 (95% C.I. 0.28-0.55). Furthermore, some autocorrelation appears to remain in the catch residuals (Appendix A).

Table 2.4.7 *Original ICES catch data and corrected catch data for North Sea herring*

Year	ICES catch (t)	Catch estimated based on 1982-1984 data and IBTS (t)
1977	46000	97547
1978	11000	130065
1979	25100	74735
1980	70764	83146
1981	174879	337059

North Sea cod

To account for unallocated removals, ICES applied a catch multiplier to reported commercial catches from 1993 to 2011 (Table 2.4.8). However, for an unspecified reasons, from the 2013 advice onwards, this catch multiplier is only applied up to 2005. Because the original correction suggests some significant misreporting after 2005, we reran SPiCT with the catch multiplier spanning from 1993 to 2011, using the corrected F as an effort index. This however does mean that the data from 2012-2017 is not included, as no catch multiplier is known for those. The result is an Fmsy in ICES currency of 0.69 (95% C.I. 0.46-1.13).

Table 2.4.8 *North Sea cod catch and Fbar, corrected according to the listed catch multiplier*

Year	Total catch	Fbar 2-4	Catch multiplier
1993	149343	0.891	0.97
1994	153430	0.906	1.1
1995	185907	0.934	1.25
1996	165545	0.955	1.06
1997	166375	0.961	0.96
1998	140787	0.98	0.8
1999	100912	0.999	0.86
2000	101926	0.995	1.04
2001	90853	0.956	1.52
2002	88521	0.926	1.27
2003	60718	0.901	1.88
2004	47620	0.857	1.33
2005	47052	0.8	1.34
2006	41606	0.723	1.24
2007	56106	0.669	1.3
2008	54122	0.63	1.09
2009	56897	0.602	1.16
2010	61821	0.583	1.21
2011	66903	0.572	1.43

Regime shift

During the available time series of a stock, it is possible that the stock may have undergone a regime-shift. It is important take this into account and correct for this if possible, so that Fmsy reference points are given that reflect the current state of the stock.

North Sea cod

The gadoid outburst can be seen as a clear regime shift for North Sea cod, during which time there were multiple abnormally-strong year classes. The last exceptionally-strong year class of NS cod could be considered to be the 1980 year class (Figure 2.4.4). This could then also be considered as the end of the gadoid outburst for NS cod.

There are essentially three ways to deal with this regime shift in SPiCT. One is to simply remove all years of the gadoid outburst from the time series. Secondly, we could only remove the years when in spite of high fishing, SSB still increased or remained unchanged. The last is to use the MSYregime functionality, which enables the estimation of multiple MSY regimes in different time periods.

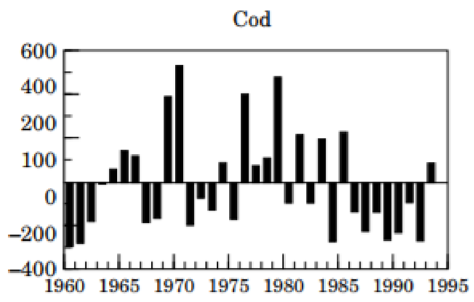


Figure 2.4.4 *"VPA estimates of year-class strength (millions of 1-group fish), shown as deviations from the long-term artithmetic mean" Figure and caption taken from: Hislop, J. R. (1996). Changes in North Sea gadoid stocks. ICES Journal of Marine Science, 53(6), 1146-1156.*

If we want to remove the entire gadoid outburst from the SPM, we need consider which years to cut out. We could cut out all years up to 1980, but the 1980 year class will still play a significant role in the catch over the following years. Therefore, we ran SPiCT for three different start years: 1981, 1986, and 1991. Using F as a proxy for effort, the only start year that gave reliable results was 1981, with an Fmsy in ICES currency of 0.59 (95% C.I. 0.32-1.68).

Alternatively, there are clear periods where an increase in fishing mortality coincides with an increase in SSB (Figure 2.4.5). We could assume these trends to be consequences of the gadoid outburst, and see what happens when we remove those specific years. These are the years 64-68 and 79-82, while the years 70-72 could be considered to be removed because of the great increase in fishing mortality with only a slight decrease in SSB. However, none of scenarios of individual year removals seem to give any improvement of the reference points compared to above (see North Sea cod results source file).

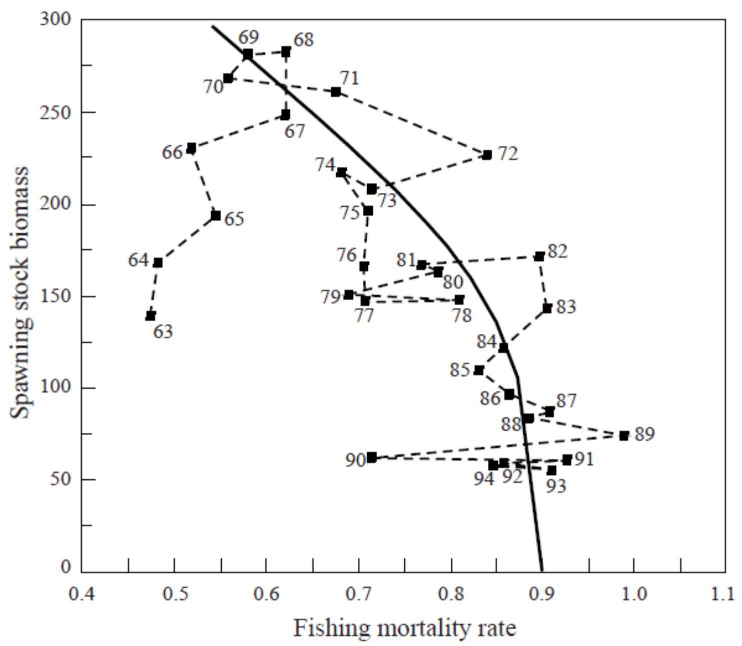


Figure 2.4.5 *Relationship between F and SSB for North Sea cod, shown from 1963 to 1994. From Cook, R. M., Kunzlik, P. A., HISLOP, J., & Poulding, D. (1999). Models of growth and maturity for North Sea cod. Journal of Northwest Atlantic Fishery Science, 25, 90-100.*

Lastly, the MSYregime functionality of SPiCT was used. For this, a choice had to be made in which year the regime would shift. The best results were obtained for having the new regime start in 1986, with the production curve no longer being slanted toward the right (Figure 2.4.6). However, the confidence intervals for the reference points are still very wide, with Fmsy in ICES currency for the first regime being 1.13 (95% C.I. 0.59-2.23) and for the second regime being 0.50 (95% C.I. 0.21-1.19).

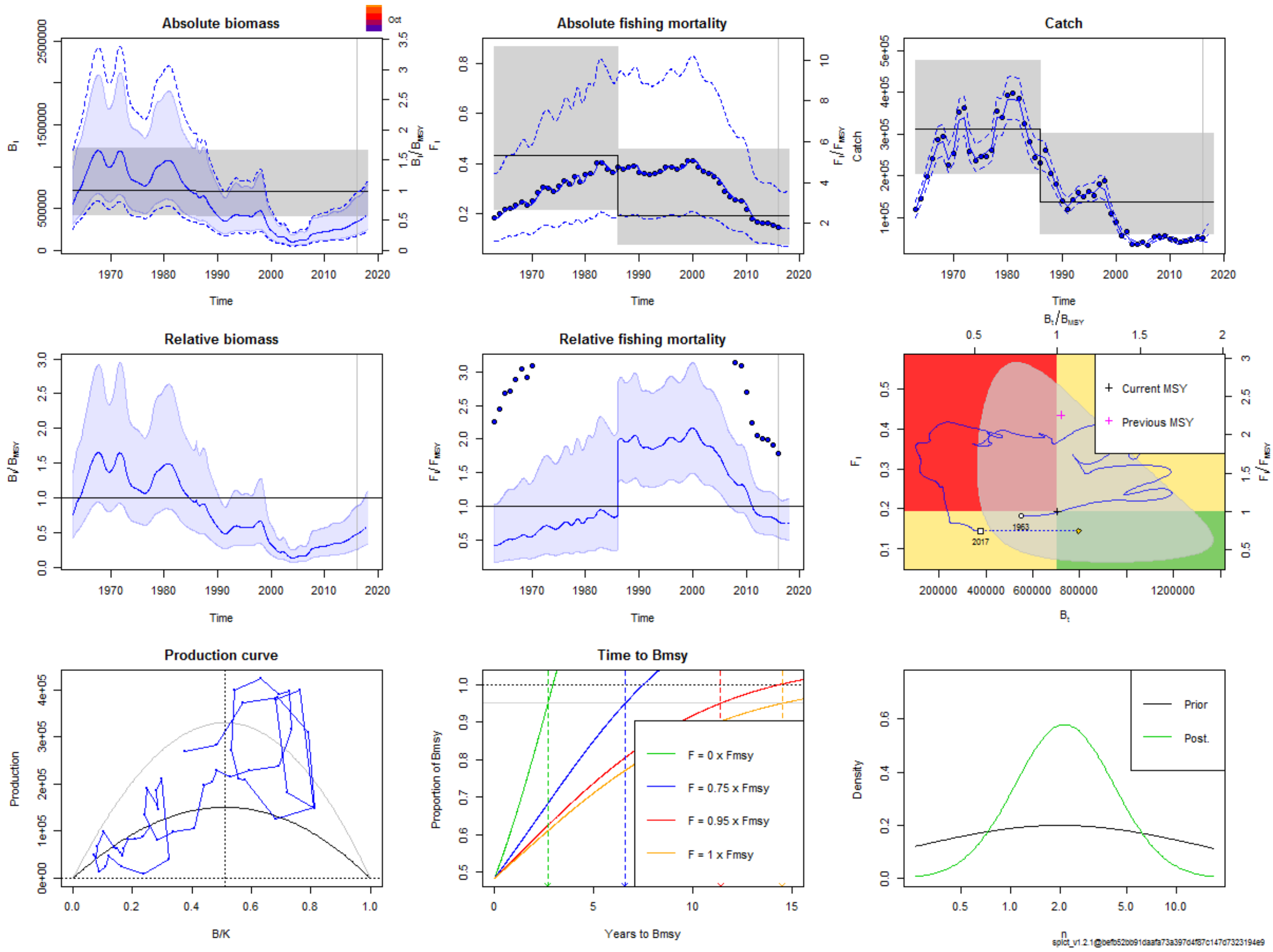


Figure 2.4.6 *SPiCT results for North Sea cod with the MSYregime functionality starting a new MSY regime in 1986. F was used as an effort proxy here.*

In an effort to try and improve the reliability of the results, we also fitted SPiCT to the North Sea cod data corrected for misreporting (up to 2011), as described above. Assuming that no misreporting took place from 2012 onwards, we attached the 2012-2017 data for NS cod to the data from ACOM 2012. We then fitted this data to SPiCT using corrected F as an effort proxy, using the MSYregime functionality with the new regime starting in 1986. However, this did appear to increase the reliability, and instead only widened the confidence intervals (Figure 2.4.7), with Fmsy in ICES currency for the first regime being 0.84 (95% C.I. 0.47-1.56) and for the second regime 0.48 (95% C.I. 0.17-1.49).

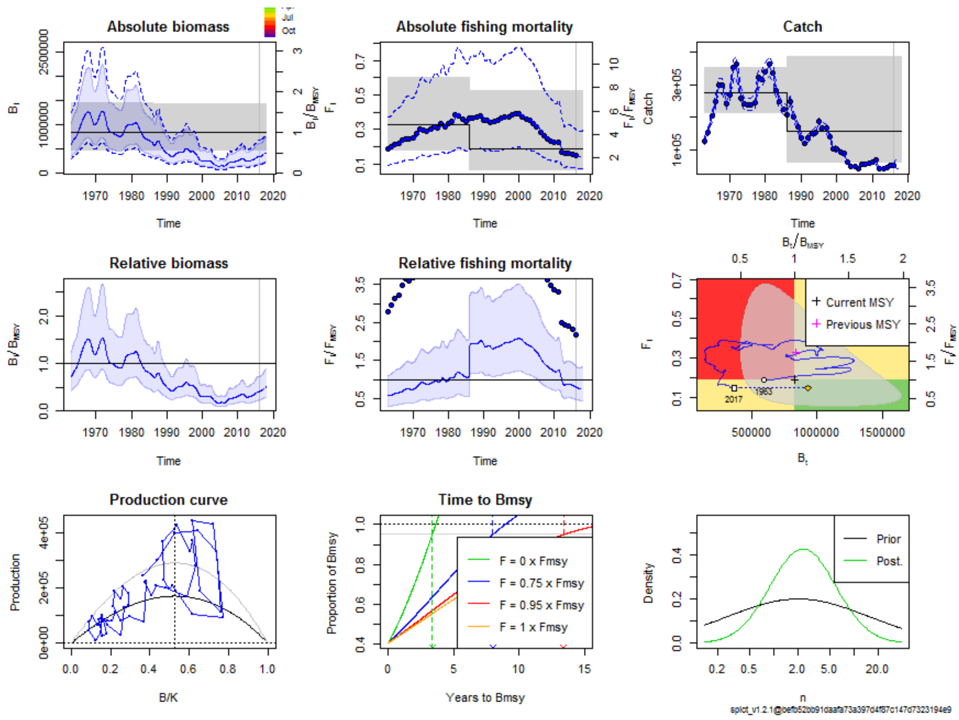


Figure 2.4.7 *SPiCT results for North Sea cod data corrected for misreporting between 1993 and 2011, with the MSYregime functionality starting a new MSY regime in 1986. F was used as an effort proxy here.*

North Sea plaice

North Sea plaice developed an exceptionally strong year-class in 1986, with peaks in catches over the following years. The years 1986-1990 were therefore removed from the catch time-series, and the remaining dataset was fitted to SPiCT with catch/F as the biomass index. This results in an Fmsy in ICES currency of 0.53 (95% C.I. 0.22-1.27). This is higher than the original estimate (Table 2.4.5), but still with a very wide confidence interval.

NEA cod

SPiCT was used to test the sensitivity of the estimated Fmsy to the length of the time series. Catch/F was used as biomass index. From Figure 2.4.8 it can be seen that the whether the time series is 1946-1970, 1946-1975, …1946-2010 it gives the same Fmsy (around 0.50 in tke ICES F currency). If 1946-2015 is used it drops a bit to Fmsy = 0.43. This sensitivity to the last about 5 years might have something to do with the temperature increase observed in the Barents Sea which means that cod have got substantial new sea bottom areas to feed in and therefore could increase more than expected with the recent reduction in fishing pressure. If that bis the case then the Fmsy estimated from the period until 2010 is probably closest to the true Fmsy value also in the new regime but MSY of course will be larger than predicted for the pre 2010 time.

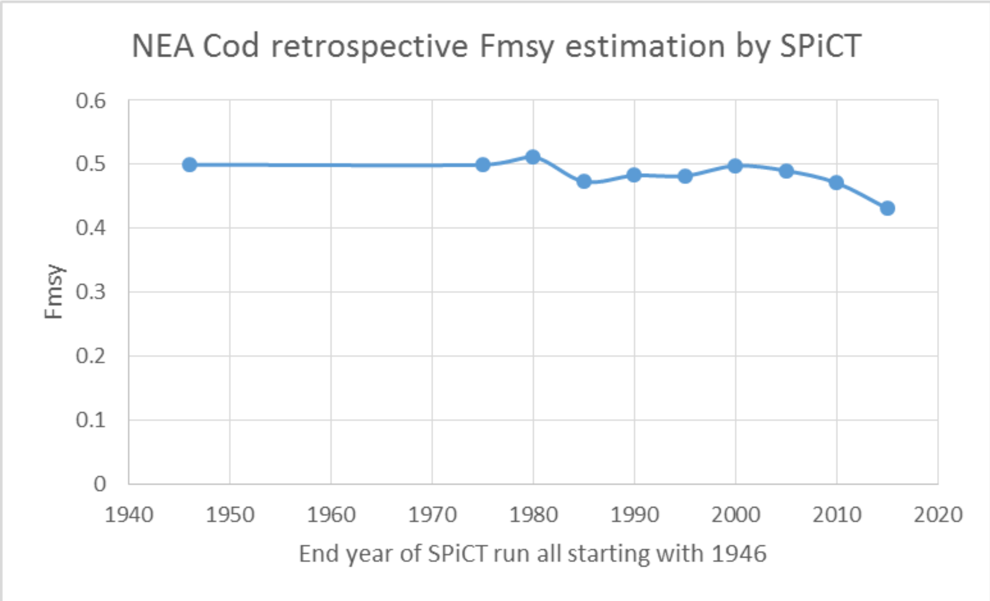


Figure 2.4.8 *Fmsy (in the ICES currency) estimated with SPiCT for different end year of the time series. Each time series starts in 1946. For instance the point at 1985 means that the time series from 1946-1985 have been used.*

The sensitivity to a changed regime is more clearly seen in Figure 2.4.9. These Fmsy estimates are based on time series all ending in 2015 but starting in different years. The point at 1946 of 0.43 is the same analysis as in plot in Figure 2.4.8 for the point at 2015, i.e. based on the whole time series 1946-2015. When the first 10 years are dropped from the analysis the Fmsy decreases to 0.40 and are pretty stable until the first 40 years are dropped. Then also the CV increases substantially, probably due to the slight regime shift and shortness of time series. The model have difficulties finding a well-defined solution.

This showed that if the time series are shorter than about 30 years and we have a regime shift the SP modelling gets into trouble.

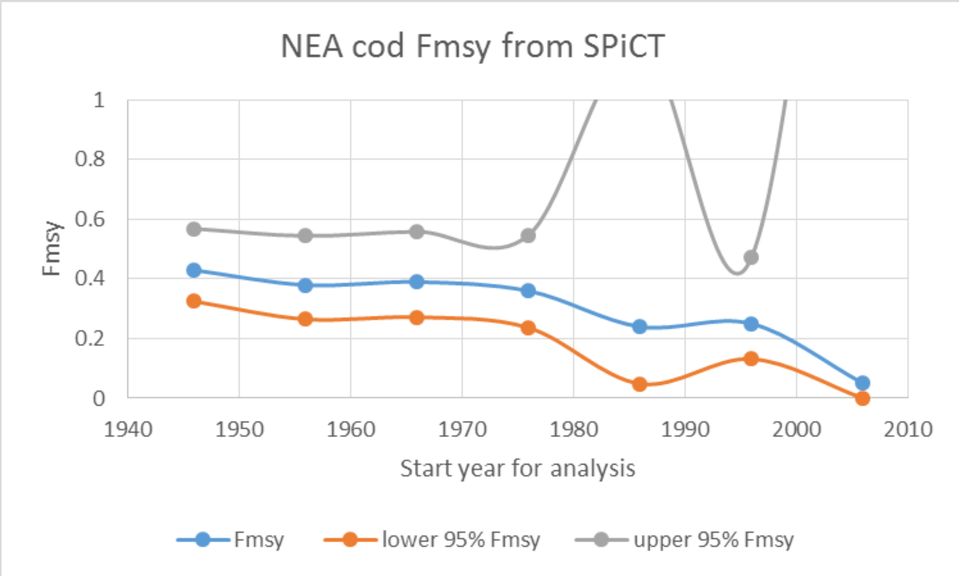


Figure 2.4.9 *Fmsy as a function of start year in the time series. This plot s quite similar to the plot in Figure 2.4.8 but instead of all time series starting in 1946 they now start at different years and all ends at 2015. For instance the point at 1986 is Fmsy calculated based on the time series 1986-2015. The 95% confidence intervals are also shown.*

It should also be noted that the SP SPiCT modelling for the time series 1946-2010 and for whole time series are very well behaved, Fmsy estimated with a low CV of about 0.1, and can go right into any text book on fish population dynamics (Figure 2.4.10-11).

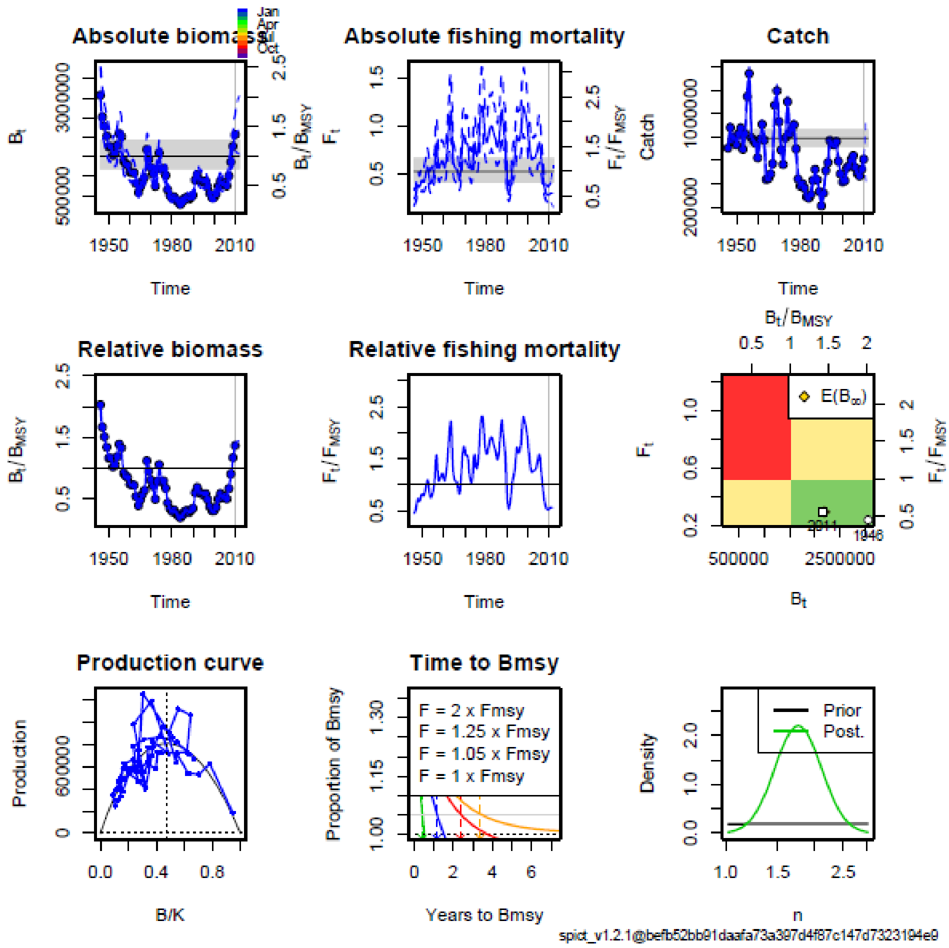


Figure 2.4.10 *Diagnostic from the SPiCT run with data from 1946-2010.*

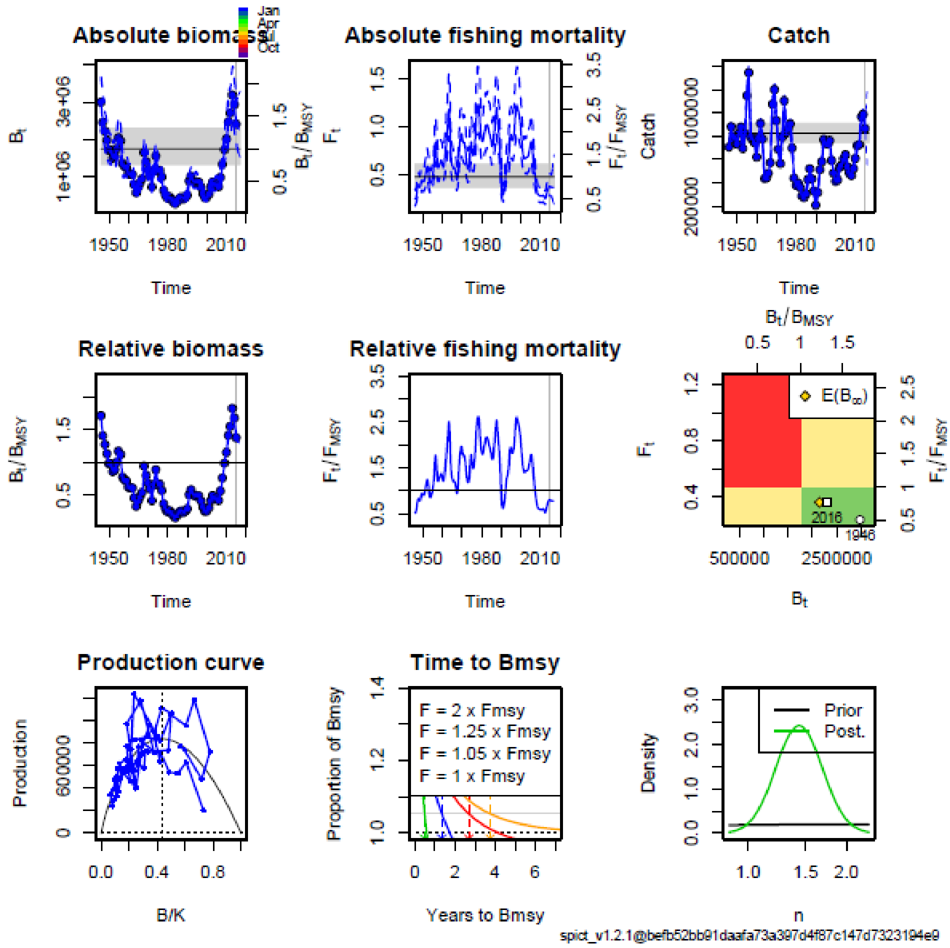


Figure 2.4.11 *Diagnostic from the SPiCT run with data from 1946-2015.*

2.5 WP5 Density dependent growth, maturity and cannibalism

There seems to be an increasing attention in the science community on density dependent (DD) effects on growth, maturity, and cannibalism. Several new papers on the issue have been produced and many of these are uploaded to the Dropbox site of the present project. Since last meeting it was discovered that even old Baranov (1918) were very well aware of it. He writes on p. 30:

As far as the plaice fishery is concerned, at the present time there is evidence to favor the second hypothesis. A whole series of investigators, admitting the intensive removal of adult plaice, remark that the shallow banks are overpopulated with young plaice, suffering, apparently from a scarcity of food. An experiment of W. Garstang, done in the year 1904, will serve as a direct confirmation of the condition described. He transplanted young plaice, caught in proximity to shore and provided with a mark, to the Dogger Bank, and discovered that fish which near shore grow not more than 5-7 centimeters a year, on the Dogger Bank grew in 7 months an average of 12-13 centimeters. So too Peterson (14) reports that the young of plaice which near shore grow 4-5 centimeters a year at most, grow 8-11 centimeters a year in the Skagerrak, where the number of plaice is markedly less.

At last meeting the case about Fmsy estimation for North Sea cod was discussed. Figure 2.5.1. below show how dependent estimates of Fmsy are on including DD for more than recruitment.

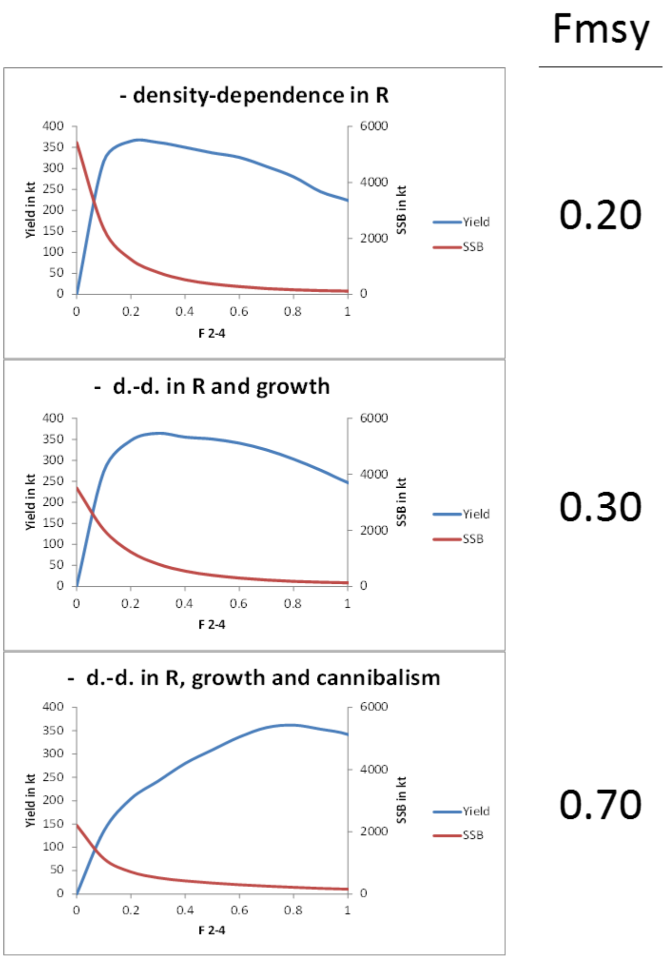


Figure 2.5.1 *NSea cod. Yield and SSB vs F for three scenarios of stock dynamics. Top panel only density dependence in R per SSB (the S-R model included). Middle panel DD in growth added. Bottom panel DD in growth and cannibalism added.*

Similar analysis were done for NEA cod, cod at Iceland, Baltic sprat, summer flounder and mackerel. At last meeting we listed furthermore the NSea plaice, NSea sole, and Northern hake.

NEA cod

Data and software used were as in ICES IBP ARCTIC COD REPORT 2017 and ICES ADVISORY COMMITTEE ICES CM 2017/ACOM:29, and ICES. 2015. Report of the Benchmark Workshop on Arctic Stocks (WKARCT), 26–30 January 2015, ICES HQ, Denmark. ICES CM 2015\ACOM:31. 121 pp. Figure 2.5.2 shows that it is very much the same story as for cod NSea, Fmsy increases form a low value of about 0.20 to 0.60 when all three DD factors are included.

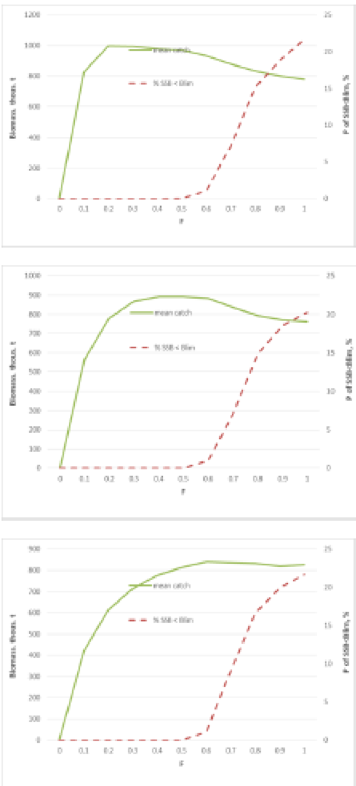


Figure 2.5.2 *NEA cod. Yield and SSB vs F for three scenarios of stock dynamics. Top panel only density dependence in R per SSB (the S-R model included). Middle panel DD in growth added. Bottom panel DD in growth and cannibalism added.*

For NEA cod even an F = 1.5 would give 98% of the MSY. This indicate that a management strategy of fishing the surplus production so that each year the surviving SSB is at Bpa is one close to the Fmsy strategy, and it would have the advantage that there will not be any extra biomass out there in the sea just burning ecosystem production for maintenance metabolism and predating on preys.

It would be interesting to try this type of calculation on other stocks, because it seems likely to be a general phenomenon.

It also shows that the current management strategy for short lived stocks using exactly this approach, probably is very close to an MSY strategy.

Cod Iceland

For cod Iceland the NEA Cod Visual basic excel program ”NE_PROST-ICEcod simple.xlsx” was used. Based on the S-R data from the assessment (Figure 2.5.3), Blim was set to 207,000t from segmentet regression (Hockey stick). Bpa set to 330,000t. HCR: ICES default rule used. DD in was from weight from Danielsson et al 1997. WEST “…. is an almost linear decrease from 1.0 to 0.7 for SSB in the historical range of 500,000 to 1.5 million tons.”

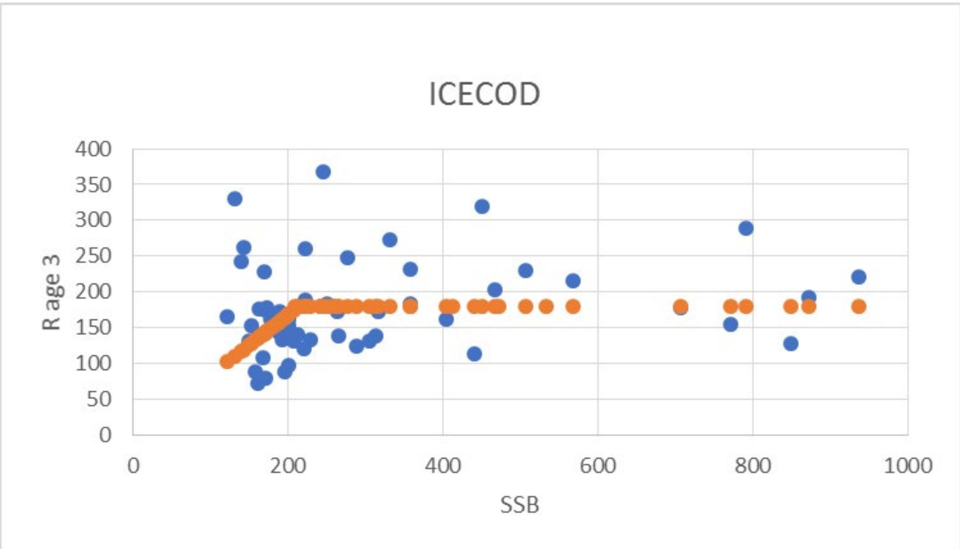


Figure 2.5.3 *Cod Iceland. S-R plot with fitted segmented regression line.*

Cannibalism as for Barents Sea cod 1970- 1985 based on Bjarte Bogstad, et al 1994 and ICES IBP ARCTIC COD REPORT 2017, ICES ADVISORY COMMITTEE ICES CM 2017/ACOM:29 and ICES. 2015. Report of the Benchmark Workshop on Arctic Stocks (WKARCT), 26–30, January 2015, ICES HQ, Denmark. ICES CM 2015\ACOM:31. 121 pp. The resultant relationship between M2 and biomass of age 6+ is given in Figure 2.5.4.

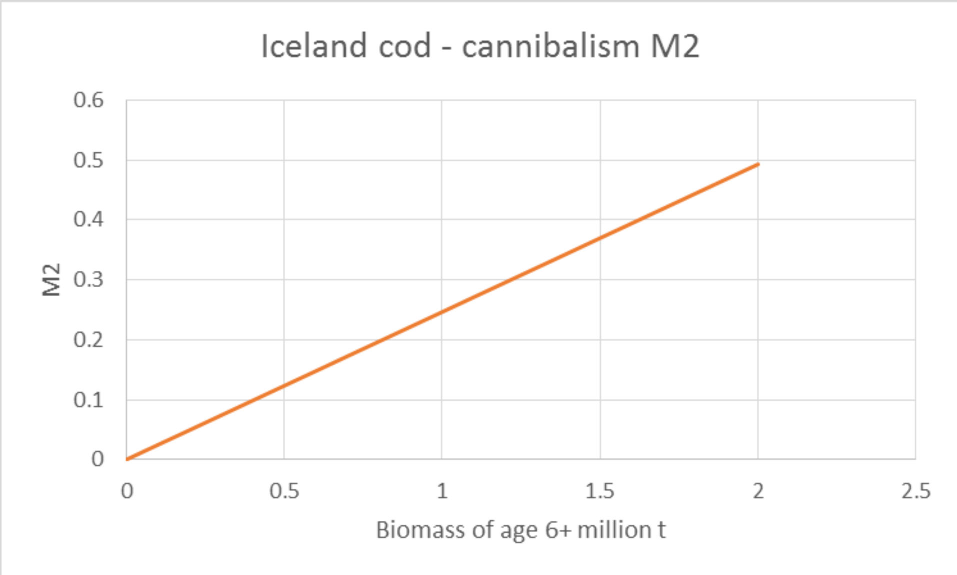


Figure 2.5.4 *NEA cod. Relation between M2 (predation mortality) of age 3 cod and biomass of age 6+.*

The biomass of 6+ is on average 1.38 times SSB for this stocks. Other input to the calculations shown in Appendix 5. Results are given in Table 2.5.1. It can be seen that it is the same pattern as for NSea cod and NEA cod, a much higher Fmsy when all density dependent factors are included in the calculations.

Table 2.5.1 *Cod Iceland. Results of Fmsy calculations for various inclusions of density dependent factors.*

Model	F msy	Variability in TAC by year according to Key-run	Catch according to Key-run '000 t	SSB according to Key-run '000t	TSB according to Key-run '000t
Key-run	0.70	55%	330	345	1170
Key-run without DD growth	0.65	38%	330	367	1193
Key-run without cannibalism	0.55	24%	323	429	1263
Key-run without cannibalism and DD growth	0.40	15%	305	568	1398
F current = 0.26	-	13%	268	803	1620

Mackerel

The ICES WKMACMSE_2017 workshop looked into including DD in growth when estimating Fmsy for this stock. They found again as expected that Fmsy is higher when DD is taken into account (Figure 2.5.5).

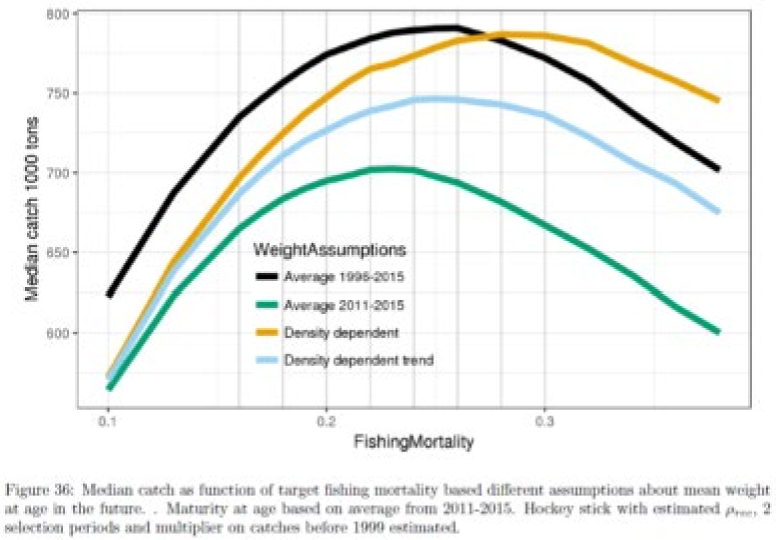


Figure 2.5.5 *Mackerel. Yield vs F for different assumption of DD in weight at age. From ICES WKMACMSE (2017).*

From the same analysis the weight at age 6 mackerel at selected F levels are shown in Figure 2.5.6. It can be seen that it increases from 425 g at F = 0.18 to 450 g at F = 0.40.

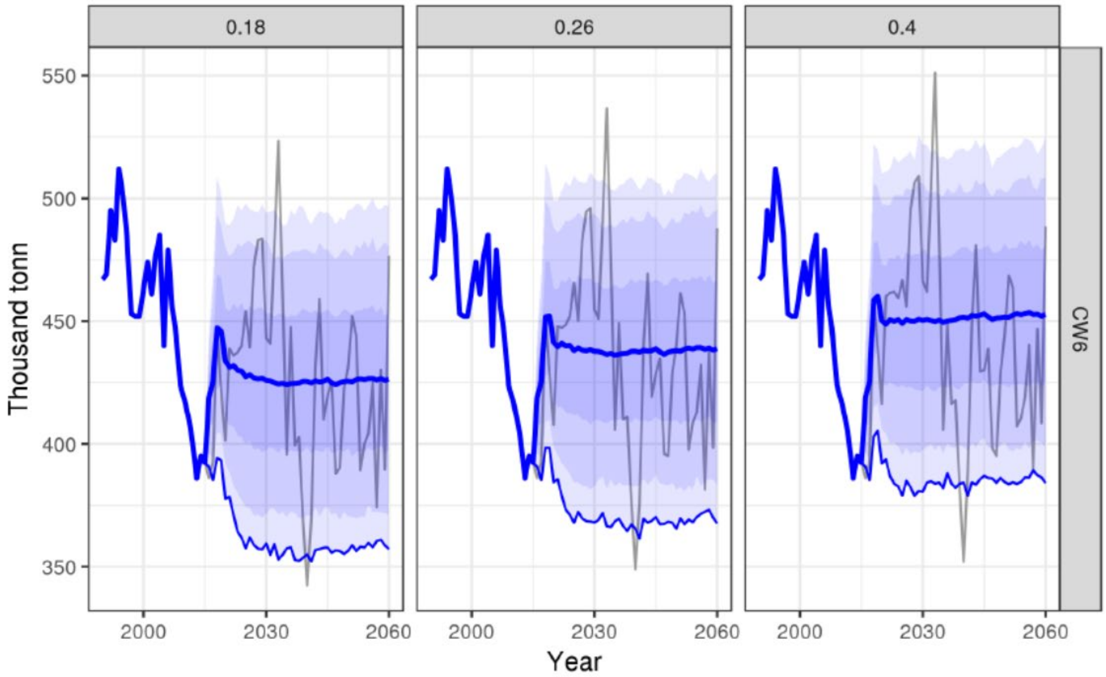


Figure 41: Development of mean weight at age 6 in catches for 3 different target fishing mortalities. Hockey stick function with autocorrelation estimated. $B_{trigger} = 1940$. Density dependent weights without trend

Figure 2.5.6 *Mackerel. Weight of age 6 mackerel at different F levels. From WKMACMSE (2017). Note that the unit on the Y-axis should be gram and not tons.*

For some fleets large mackerel over 500g is a target. The catch of plus 500g mackerel by year is shown in Figure 2.5.7. It shows that this amount is low in recent years, and this is consistent with the density dependent growth as the stock size is large in recent years.

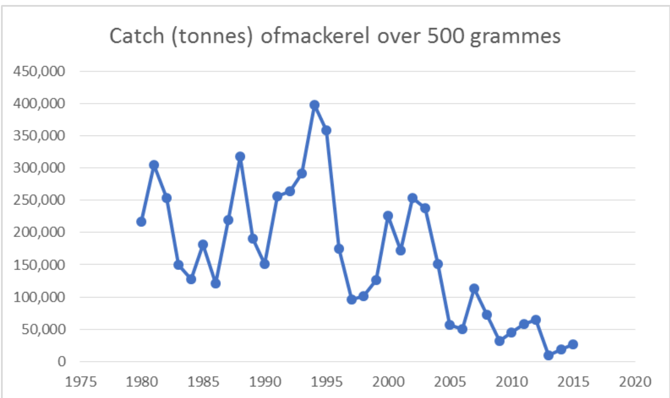


Figure 2.5.7 *Mackerel. Catch in weight of +500g mackerel. Data from ICES WGWIDE 2016.*

Using the PROST software the Y vs F and SSB vs F calculated gave quite similar results as the ICES WKMACMSE (2017) results, or rather vice versa as these PROST calculations were done in 2016 base on ICES assessments in 2015. Table 2.5.2 shows the results. Fmsy is again higher when dd is included. This time 0.40 compared to 0.30.

Table 2.5.2 *Mackerel. PROST calculations based on ICES 2015 assessment data. West data fitted by a functional regressions of SSB.*

Simulation scenarios	Fmsy	Bmsy kt	MSY kt	B0 kt	TAC variability from year to year	Risk to get below Blim
No density dependence	0.30	3300	730	8380	10%	<<5%
Density dependent growth	0.40	2900	790	6890	11%	<<5%

Baltic sprat

From Horbowy and Luzenczuk (2017) it is shown that Fmsy increase from about 0.30 to 0.50 when including growth into the calculations. Cod is an important predator on sprat and they assumed the cod stock constant. The M2 is then only dependent on the biomass of sprat and there is a small and probably artificial negative relationship between M2 (not cannibalism here but cod predation) and sprat biomass when cod biomass is kept constant. This is because the SMS model assumes cod consumption to be constant, independent on amount of food present, which is not likely. It is more likely that cod will east a little more when the sprat biomass is high. Anyway the effect is not large and can be ignored in the present context.

Fig. 9. F_{MSY} estimates from deterministic and stochastic simulations based on different options: density-dependent mass and natural mortality (both w and M), density-dependent w (only w), density-dependent M (only M), and constant w and M (w and M constant). The stochastic F_{MSY} is the F that maximizes mean stochastic yield. Cod biomass is assumed at 200×10^3 t.

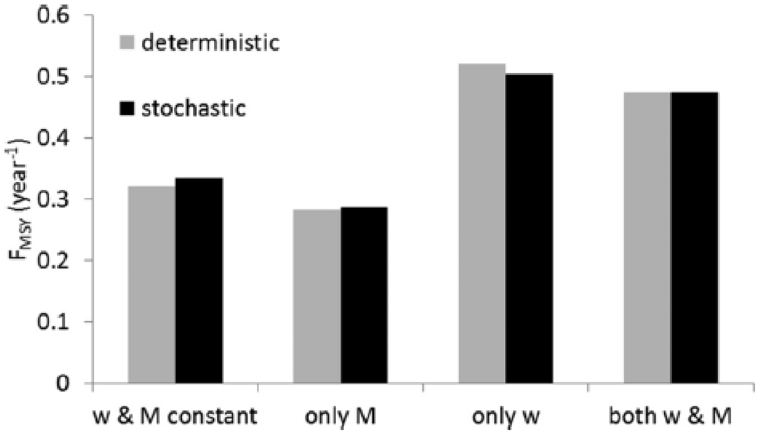


Figure 2.5.8 *Sprat Baltic. From Horbowy and Luzenczuk (2017).*

A dozen stocks from US east coast

A small meta-analysis was performed on 12 stocks from the US east coast waters. American plaice Gulf of Maine-Georges Bank:

Cod Georges Bank

Cod Gulf of Maine

Haddock Georges Bank

Haddock Gulf of Maine

Pollock

Tilfish

White hake

Winter flounder Georges Bank

Winter flounder Southern New England-Mid Atlantic

Witch flounder

Yellowtail flounder Gulf of Maine

Yellowtail flounder Southern New England-Mid Atlantic

Menhaden

Striped bass.

It analysed the effect of including density dependence in 12 New England fish stocks. An example of DD in growth is shown in Figure (2.5.9). The analysis showed that Fmsy increased in all 12 cases and the increase was on average 20% (Figure 2.5.10).

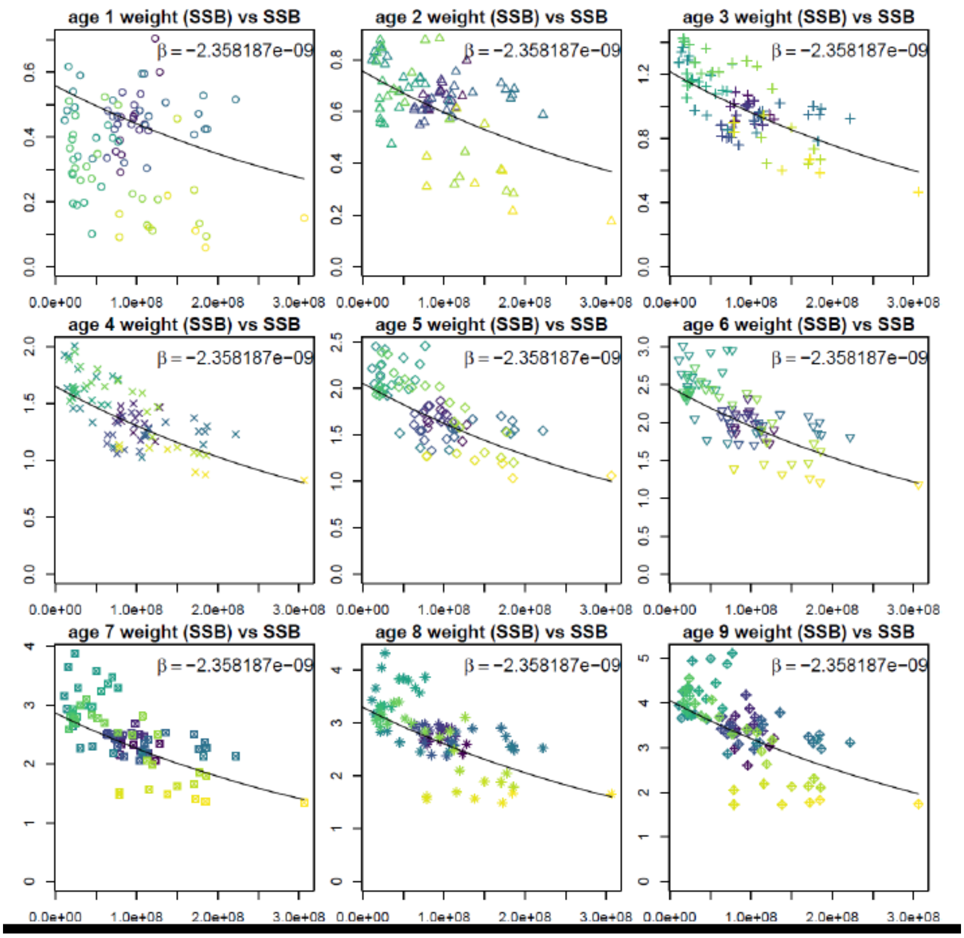


Figure 2.5.9 *Haddock Georges Bank. An example of density dependent growth.*

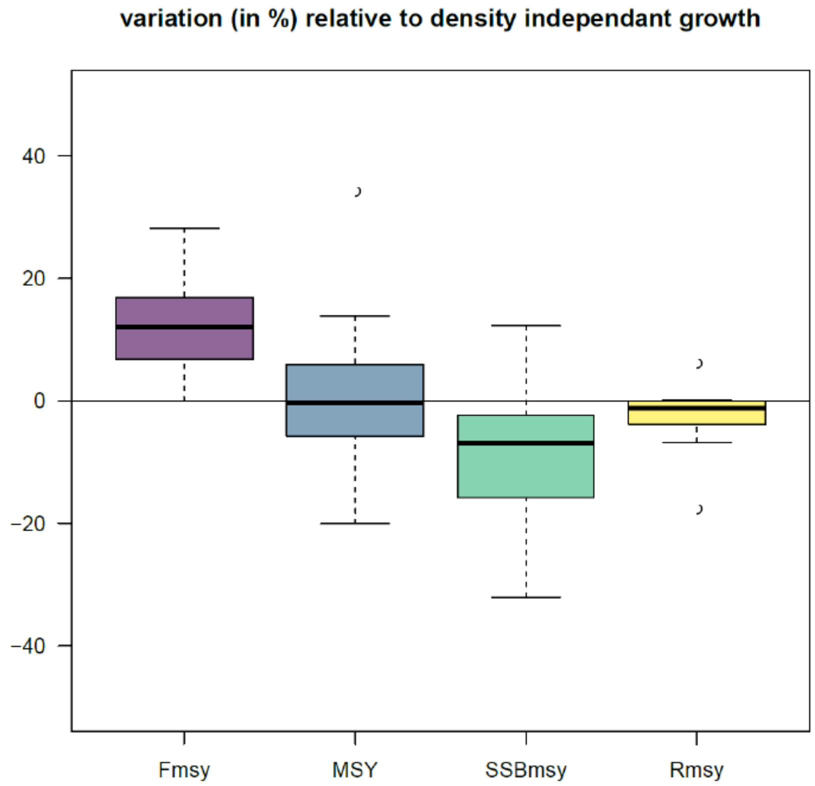


Figure 2.5.10 *For 12 New England (USA Northwest Atlantic) fish stocks. Changes in Fmsy, MSY, SSBmsy and Rmsy when including density dependent growth.*

A small meta-analysis of density dependence in 6 important ICES fish stocks

The idea is to look at all ICES data rich stocks and to see how much evidence there is for density dependence in growth in these stocks based on ICES assessment data – mainly the data matrices called WEST (WEight at age in the STock). The following stocks have been considered in the first round of analyses:

- North Sea (NS) cod
- NS plaice
- NS sole
- Blue whiting
- Mackerel
- Icelandic cod

Next, based on discussion of presented results, other stocks will be analysed, taking into account comments and suggestions from present evaluations. Two measures of growth changes were considered:

A. **Average (over ages, a) „normalised" increment in weight within year (t) or cohort (year-class, yc)**

(1) $Av.Incr_t = average_{over\ a}(\Delta w_{t,a})$

(2) $Av.Incr_{yc} = average_{over\ yc}(\Delta w_{t,a})$

where „normalised" increment in weight at age a in year t, $\Delta w_{t,a}$, is defined as

(3) $\Delta w_{t,a} = w_{t+1,a+1}^{1/3} - e^{-K} w_{t,a}^{1/3}$ (red part shows the difference from standard definition of increment)

Reciprocal of such increment may be considered as linearly dependent on stock size (see slide 11, Methods, some details), the multiplier $\boldsymbol{e^{-K}}$ makes it „independent" on age, the power *1/3* leads to linearity (K is from von Bertalanffy eq.)

B. **Relative weight at age** (in relation to average weight at age over entire time series)

(4) $RELw_{t,a} = w_{t,a}/average_{over\ t}(w_{t,a})$

Four options of possible density dependence in growth in relation to biomass & recruitment were considered:

Yearly changes

1. average (over ages) yearly „normalised" increment in weight as dependent on
   a) TSB (total stock biomass)
   b) SSB (spawning stock biomass)

Cohort effects (changes over entire cohort)

1. average „normalised" increment in weight over entire cohort as dependent on recruitment abundance
2. average relative weight over entire cohort as dependent on TSB (similar to Cook et al. 1999, J. Northw. Atl. Fish. Sci., Vol. 25: 91–99)

The results are shown in Table 2.5.3.

Table 2.5.3 *Results of meta-analysis of density dependent growth of 6 ICES stocks.*

Summary of results

Summary of DD (density dep.) effects for stocks, when all data are included

	NScod		NSplaice		NSsole		Bluewhiting		Mackerel		Iceland Cod	
	R^2	slope	R^2	slope	R^2	slope	R^2	slope	R^2	slope	R^2	slope
Yearly increment vs												
TSB	<0.1	ns	0.22	p<.001	<0.1	ns	0.2	p<.01	<0.1	ns	<0.1	ns
SSB	<0.1	ns	0.21	p<.001	<0.1	ns	0.2	p<.01	<0.1	ns	<0.1	ns
Cohort effects vs												
Recr.	0.19	s (+)	0.11	p=0.02	<0.1	ns	0.25	p<.01	<0.1	ns	<0.1	ns
TSB	0.25	s (+)	<0.1	ns	<0.1	ns	0.73	p<.001	<0.1	ns	<0.1	ns

DD effects in growth for NSplaice & BW

Summary of DD after constraining ages, deleting outliers (see action taken)

	NScod		NSplaice		NSsole		Bluewhiting		Mackerel		Iceland Cod	
	R^2	slope	R^2	slope	R^2	slope	R^2	slope	R^2	slope	R^2	slope
Yearly increment vs												
TSB	<0.1	ns	0.22	p<.001	<0.1	ns	0.2	p<.01	0.13	p=0.04	<0.1	ns
SSB	<0.1	ns	0.21	p<.001	<0.1	ns	0.2	p<.01	0.14	p=0.03	<0.1	ns
Cohort effects vs												
Recr.	0.20	s (+)	0.11	p=0.02	<0.1	ns	0.25	p<.01	0.1	ns	<0.1	ns
TSB	0.28	s (+)	<0.1	ns	<0.1	ns	0.73	p<.001	<0.1	ns	<0.1	ns
Remarks, action taken	ages 3-9		no action		ages2-10		no action		ages2-11		ages 4-11	

- Now DD effects also for **mackerel**.
- For NScod, NSsole, & Iceland cod improved diagnostics but still no DD effects in growth

(+) = positive slope, while negative is expected
s/ns = significant, not significant

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For one of the stocks the slope was opposite of what was expected from DD, and for five stocks the slope was as expected, and significantly so for 3 stocks. Bering in mind that the dynamic range of SSB or TSB has not been very large historically compared to what is expected from forecast simulations used to calculate Fmsy this is adding an example to the already large amount of indications that DD is real and needs to be taken into account when calculating Fmsy. More analysis will be performed in the coming months on many more data rich ICES stocks.

Guidelines for use of density dependent growth data

It was suggested that the way to do the meta-analysis and the way to use DD in growth in Fmsy calculations should follow the guidelines given below:

1. Choose common response and dependent variables to use for all stocks:

a. weight at age a in year t, wat, normalized to the mean (or the first year)

b. SSB is available as a measure of density for for most stocks.

2. Choose a model equation:

Hyperbolic (Horbowy and Luzenczyk 2016) $w_{a,t} = a/(b+SSB)$

Exponential (Zimmerman et al. 2018) $w_{a,t} = \propto e^{-\beta SSB}$

(both equations will likely give similar fits)

3. Filter ages (if necessary) with a consistent filter

4. Fit model with a common shape parameter for all ages to increase the power of the estimation

5. Fit model to a range of stocks, for which weight-at-age data are available.

6. Try to explain the results. Why do some stocks exhibit density-dependent growth?

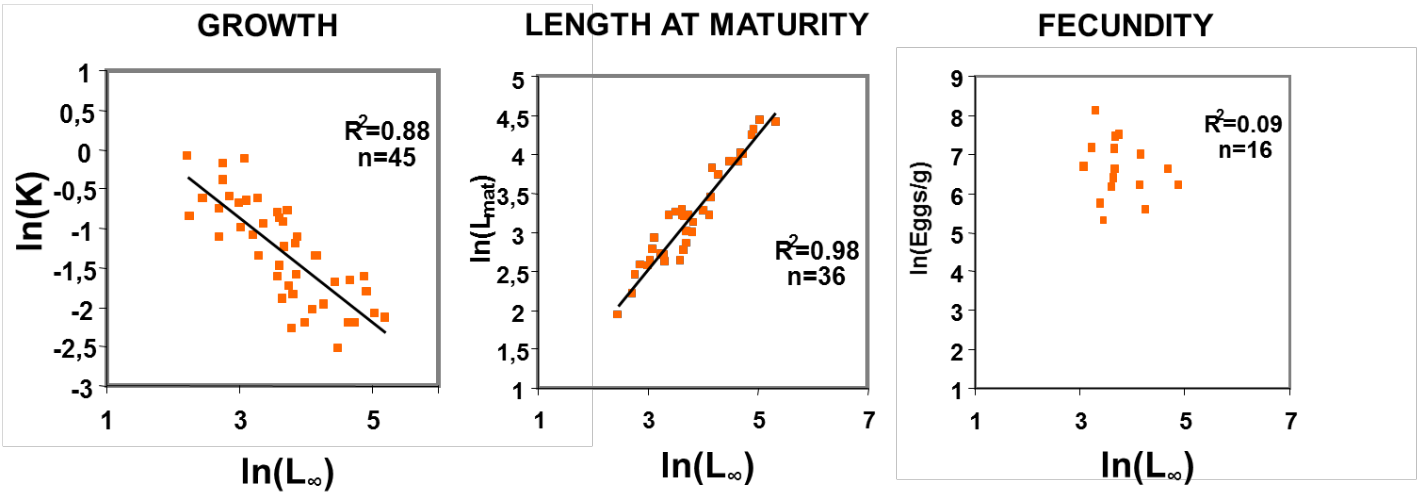
e.g. large contrast in stock size, benthic feeders, etc.

7. Calculate Fmsy with and without density-dependent growth for contrast.

2.6 WP6 Life history parameters relevant for Fmsy.

John Pope and Henrik Gislason were invited to the meeting, but Henrik had to apologize due to sickness in the family. John co-operated with Henrik and could present his work as well.

There are fundamental life history features which any management strategies have to respect. One of these is shown in Figure 2.6.1. It is the fact that fish with a large Linf and large size at maturity are producing the same number of eggs per kg as small species, but both in the steady state have to produce two off springs only. Thus, the natural mortality for large species by size must be higher than for small species.



$$K = 3.15 \cdot L_\infty^{-0.64} \qquad L_{mat} = 0.72 \cdot L_\infty^{0.93} \qquad \overline{E} = 977\ eggs/g$$

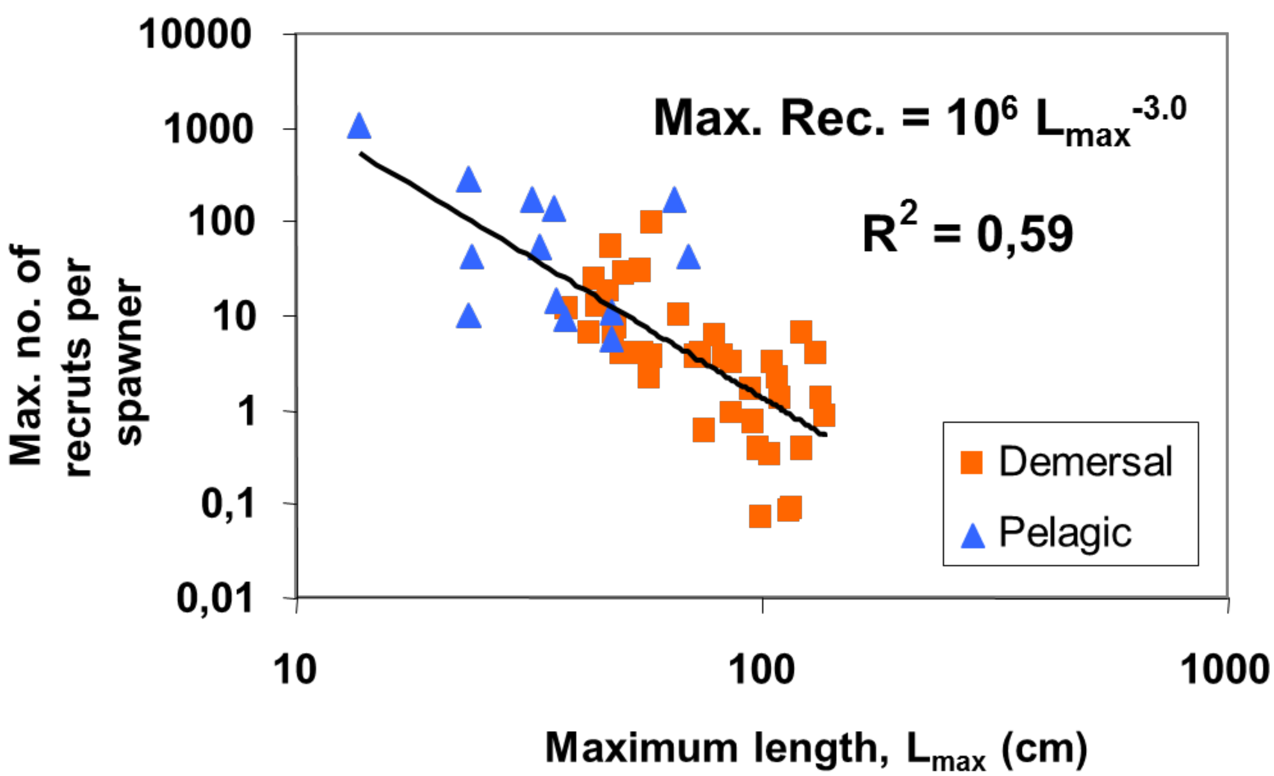


Figure 2.6.1 *Max no of recruits per spawner biomass vs Lmax. Note that the y-axis label miss the biomass term. Based on data for 55 northeast Atlantic fish stocks (Denney et al. 2002).*

The basic equations are given in Table 2.6.1. Some needs to be adjusted basically due to the feature described in Figure 2.3.2 (lower panel right hand side), i.e. the overall ecosystem fishing pressure.

In the present project we would like to establish a link between the life history parameters and Fmsy in order to be able to “export” Fmsy values from one stock to another. Linf seem to be the most relevant one, given that the stocks are from the same ecosystem. One should for instance probably not export an Fmsy from a cod stock to a redfish stock. Export of Fmsy within the same species could be corrected by Linf, but K might also be considered. Export from a cod stock to a say plaice stock might be more difficult.

Table 2.6.1 *Basic life history parameters equations.*

The basic equations

- Growth : $L = L_\infty(1-\exp(-Kt)); \quad K = 3.15 \cdot L_\infty^{-0.64}$
- Length at maturity : $L_{mat} = 0.72 \cdot L_\infty^{0.93}$
- Weight and length: $W_L = 0.01 \cdot L^3$
- Production of postlarvae: $N_{0.5} = 0{,}03 \cdot 977 \cdot 0{,}5 \cdot \sum_{L_{mat}}^{L_\infty} \overline{N}_{L,L+\Delta L} \cdot W_L$
- Numbers at size: $N_{L+\Delta L} = N_L \cdot \left(\frac{L_\infty - (L+\Delta L)}{L_\infty - L}\right)^{(M_L+F_L)/K}$
- Natural mortality: $M_{beforesettling} = 0.1 + m \cdot L^n$ (15% day for an 0.5 cm larva (Pepin 1991))

  $M_{after\ settling} = 0.1 + h \cdot L_\infty^i \cdot L^n$

Gislason, Pope, Rice and Daan(submitted)

It was concluded that further work is needed on this issue.

2.7 WP7 GLM type analysis to “export” ecosystem Fmsy

The aim is:

1) to ”spread” ecosystem/multispecies model results to other stocks
2) to “dampen” out outliers in the Surplus Production Model Results

The GLM could be like:

Fmsy = a*species*K

Fmsy = a*K*cannibal-type

Fmsy = a*M_α (natural mortality at the post maturity stage)*cannibal-type

….or?

Where cannibal-type could be a grading from “no”, “medium” to “high”. For plaice and sole would it be “no”, for blue whiting, mackerel, haddock and saithe “medium”, and for cod and hake “high”. We should probably ln transform so that the models become linear.

Maybe there should not be any difference between stocks of the same species, because a difference in K might be counteracted by a difference in R/SSB due to simpler ecosystems and less competition from other species.

It seems that there are some evidence for the situation that species constituting a large part of the biomass in an ecosystem are more exposed to DD than other species. Thus we should expect a higher Fmsy for these stocks.

If we compare North Sea cod with NEA cod, K is higher which should mean a higher Fmsy, R/SSB is lower (is it?) which should give a lower Fmsy, and it constitute a lower part of the ecosystem biomass, which should give a lower Fmsy. Thus “1” higher and “2” lower factors.

Charnov, Gislason and Pope 2013 gives this:

$$M = \left(\frac{L}{L_\infty}\right)^{-1.5} \cdot K$$

…and this generalizations:

$$M_\alpha = 0.41 \cdot A \cdot W_\alpha^{-1/3}$$

To our knowledge nobody have been trying to relate M, K and L_∞ to Fmsy. It seems to that those stocks having a high M by size also have a high Fmsy. So maybe we should look at the GLM:

Fmsy = a*X ,

where X = A* $W_\alpha^{-1/3}$.

2.8 WP8 Implementation

We managed to get a Theme session at ICES ASC 2018 accepted. It will have the title: **“Sustainability Thresholds and Ecosystem Functioning: The Selection, Calculation, and Use of Reference Points in Fishery**

Management”. It became merged with another proposal and we are 6 conveners. PICES later on found this so interesting that they asked for co-convener-ship, which we gladly accepted. Details are included in Appendix 6.

A list of contributions to the Theme session from the present Fmsy project was established and lead author and co-authors were assigned.

Fejl! Ugyldig kæde.

All are invited to be co-authors, the more the better.

2.9 WP9 Concluding work

The draft Symposium programme was further developed and several key note speakers identified. The programme now looks like this:

Day 1 – October 10, 2018

12:00 – Lunch and networking hosted by the Fmsy project

13:00 --Opening of Symposium

Welcoming Remarks. Carl Christian Schmidt, (Steen Sverdrup), NMTT Chair

13:10 -- Opening speech Ernesto Penas Lado, EU, Manuel Barange (FAO)

Chair: Jeremy Collie

13:30 -- Setting the Scene: Henrik Sparholt (NMTT)

13:55 -- Density dependence in fish populations – Jan/Katja Enberg

14:20 – The Multispecies ecosystem model knowledge – Daniel/Jeremy/Villy

14:50 -- Coffee and Networking

15:20 – The cod in Barents Sea and Icelandic Waters experience and way forward– Bjarte/

15:50 – Gunnar Surplus production models and Fmsy estimation– Jan Horbowy

16:20 – Surplus production models: RAM Legacy, Froese et al. and resulting Fmsy –Mike Melnychuk

16:50 – Results from SPiCT – Henrik/Rob

17:20 – “Exporting” the Fmsy to other stocks – Gunnar

17:50 – Closing for the day - chair

18:00 -- 21:00 Symposium Networking Buffet, hosted by the Fmsy project-- DGI Byen

Day 2 – October 11, 2018

08:00 – Breakfast and networking hosted by the Fmsy project

Chair: Villy Christensen
09:00 – Historical catch data improvements – Claus/Søren

09:30 – Case studies with Specific PROST calculations -- Rob van Gemert

10:00 – Overall conclusion from the Fmsy project and what it could it mean for fisheries management - Henrik

10:20 – Other views I on how to "bridge the gap" between the science available on these issues and the scientific advice/management. "How much varies Fmsy, what the potential impacts of keeping Fmsy constant are and the possibility of using varying Fmsy based on potential stock productivity". Joanne Morgan

10:40 – Other views II on how to "bridge the gap" between the science available on these issues and the scientific advice/management. "…" Anna Rindorf

11:00 – Coffee and Networking

11:30 -- Roundtable discussion – Should these new Fmsy be implemented in advice and management and if so how?

Moderator: Villy Christensen
Participants: Martin Pastoors (Former ACOM Chair and now Dutch Pelagic Fishers),_Ernesto Penas Lado (EU) , one of [Simon Jennings (ICES)//Anna Rindorf (DTU AQUA)], Henrik Sparholt (the Fmsy project), Mogens Skou (former Danish manager), Henrike Semmler (OCEANA, NGO), Eskild Kirkegaard (ICES).

12:45 -- Closing remarks by Carl-Christian Schmidt (NMTT Chair)

13:00 – 14:00 Lunch hosted by the "Fmsy project".

Villy C, Søren AP and Henrik S have been established as a task force to implement the symposium. Camilla Bauner has been part time employed to assist. A flyer has been produced and uploaded to the homepage. It should soon be send out.

2.10 WP10 Administration, meetings and homepage

The homepage is now up and running. The link is https://www.fmsyproject.net/.

2.11 WP11 Catch data improvements

At the Vancouver meeting (31 October-2 November 2017) we agreed to focus on the following stocks:

- Cod North Sea
- Cod NEArctic
- Herring North Sea
- Plaice North Sea
- Mackerel NE Atlantic
- (Haddock North Sea)

Mis-reporting, discarding, and high-grading have been reported for these stocks. Furthermore, there are relatively good information on what might have happened historically.

International Council for the Exploration of the Seas (ICES) assessment working group (ICES WG) catch data are the default data to be used in the present project because these are linked specifically to stocks and some un-reported catches are included, when relatively solid information about it are available. The aim of WP11 is to further improve the ICES WG data if possible. Pauly and Zeller (2015) – a "Sea Around Us" product - is an important source of information for this.

The Sea Around Us catch data reconstruction project use public available electronic landings data from the ICES as a 'reporting' baseline for their reconstruction. This baseline is then improved upon using all data accessible, including ICES stock assessments, peer-reviewed literature, grey literature and local expert opinions. Illegal, Unreported and Unregulated (IUU) catches are assessed in the form of unreported catch, over-reported catch, discarded by catch, as well as recreational and subsistence catches.

Historical catch data are very important for the results of the present project. Therefore, biases, mis-reporting, discards, and related issues will be scrutinized with the aim of correcting the time series. Issues that were sensitive decades ago, might now be possible to treat objectively and scientifically. Conversion factors for gutted fish to whole fish, overfilling fish boxes to be on the "safe" side in relation to quota management and the like, might have biased the current time series. There have been attempts in the scientific literature to correct for such things by e.g. ICES and the "Sea Around Us" project. Such sources of information will be evaluated. There will be a focus on a limited number of case studies in order to show the magnitude of influence on the obtained Fmsy reference point estimates by the project.

Appendix 6 gives a presentation and evaluation of the catch data for the above stocks for the agreed time series 1950-2016. Three catch data time series are compared:

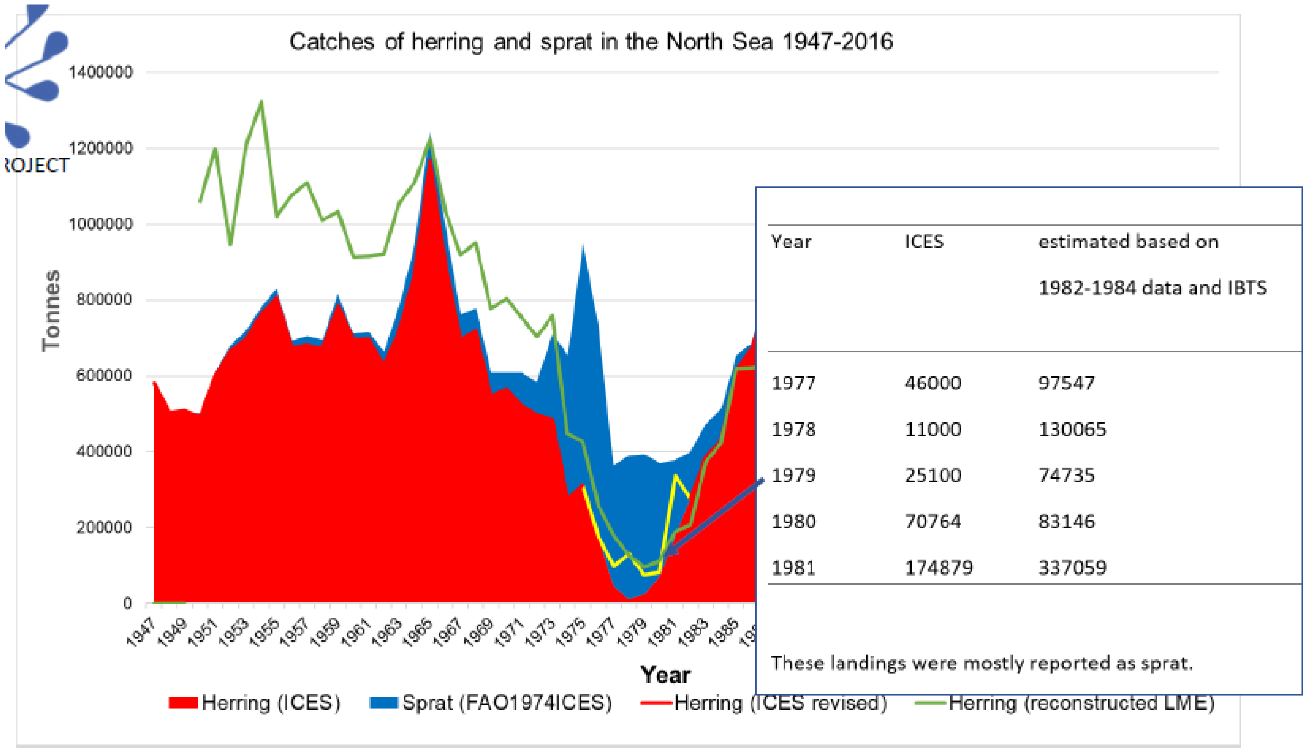
- The official catch data 1950-2010 from FAO/EUROSTAT/ICES database - ICES 2011, Copenhagen. Data can be downloaded from the ICES webpage
- Reconstructed catch data from the Sea Around Us reconstruction project. A full description is given at the Sea Around Us project webpage where the data are available for download
- The catch data used in the ICES assessment groups. Data can be downloaded from the ICES webpage.

In addition a special case was made of North Sea herring. Estimation of misreporting in 1977-1981, based on IBTS indices. The principle being that the canum data for 1982-1984 are reliable. DTU AQUA got permission in these years from the Danish Ministry of Fishery to publish the biological sampling based catch figures. Based on these years a ratio between IBTS indices by age for the same years was obtained for each age group. This ratio was used on IBTS indices for 1977-1981 to get CANUM data. These were then multiplied by WECA data to get landed tonnes by year. The estimates are:

Year	ICES	estimated based on 1982-1984 data and IBTS
1977	46000	97547
1978	11000	130065
1979	25100	74735
1980	70764	83146
1981	174879	337059

These landings were mostly reported as sprat. The spreadsheet used is given below.

		CANUM from ICES HAWG 2017.														
			1976	1977	1978	1979	1980	1981	1982	1983	1984	1985				
		0	238200	256800	NA	NA	1262700	9519700	11956700	13296900	6973300	4211000				
		1	126600	144300	NA	NA	245100	872000	1116400	2448600	1818400	3253000				
		2	901500	44700	NA	NA	134000	284300	299400	573800	1146200	1326300				
		3	117300	186400	NA	NA	91800	56900	230100	216400	441400	1182400				
		4	52000	10800	NA	NA	32200	39500	33700	105100	201500	368500				
		5	34500	7000	NA	NA	21700	28500	14400	26200	81100	124500				
		6	6100	4100	NA	NA	2300	22700	6800	22800	22600	43600				
		7	4400	1500	NA	NA	1400	18700	7800	12800	25200	20200				
		8	1400	700	NA	NA	500	6600	4700	23100	29700	29200				
		3+	215700	210500	0	0	149900	172900	297500	406400	801500	1768400				
IBTS		IBTS														
		1	823.4	269.9	594.5	167.9	316.2	494.6	798.3	1270.1	1515.6	2097.3				
		2	51.1	24.3	19.6	25.3	21.3	257.6	94.8	139.3	161.5	721.6				
		3	0.8	1.6	5.7	7.7	9.8	20.2	20.0	44.5	61.4	282.0				
		4	0.4	0.1	28.4	0.4	2.5	20.2	2.8	14.0	26.9	42.1				
		5	0.0	0.2	2.7	1.4	5.4	25.4	3.5	24.2	10.2	27.9				
		3+	1.2	1.8	36.7	9.5	17.6	65.8	26.3	82.7	98.6	352.0				
	Ratio		1976	1977	1978	1979	1980	1981	1982	1983	1984		av 1982-1984		av 1982-1984 geo	
		0	883	432	#VALUE!	#VALUE!	2553	11925	9414	8773	3325		10038		6600	shifted 1 year
		1	154	535	#VALUE!	#VALUE!	775	1763	1399	1928	1200		1697		1502	
		2	17648	1842	#VALUE!	#VALUE!	6282	1104	3159	4120	7098		2794		5106	
		3	152140	118802	#VALUE!	#VALUE!	9395	2823	11490	4858	7186		6390		7047	
		4	121495	211765	#VALUE!	#VALUE!	12839	1951	12149	7498	7494		7199		7791	
		5	718750	31674	#VALUE!	#VALUE!	4051	1124	4115	1084	7921		2108		3210	
		3+	172975	114340	0	0	8500	2629	11312	4912	8133		6284		7252	
	Estimated				1977	1978	1979	1980	1981	1982	1983					
		0	1780977	3923637	1107979	2086938	3264176	5268412	8382336	10002877	13841687					
		1	1236787	405338	892992	252168	474973	742904	1199054	1907761	2276585					
		2	260801	123875	100145	129389	108911	1315113	483922	711037	824441					
		3	5433	11057	39850	54043	68855	142023	141121	313903	432876			ICES	estimated based on 1982-1984 data	
		4	3334	397	220977	3444	19539	157755	21612	109211	209478		1976	174800	123323	
		5	154	709	8654	4423	17195	81393	11231	77606	32863		1977	46000	97547	
		3+	9043	13350	266246	68811	127891	476871	190712	600005	714683		1978	11000	130065	
	3+ minus 3 4 and 5		121	1187	-3235	6902	22301	95700	16748	99285	39467		1979	25100	74735	
													1980	70764	83146	
	weca	0	0.015	0.015	0.015	0.015	0.007	0.01	0.01	0.01	0.009		1981	174879	337059	
		1	0.05	0.05	0.05	0.05	0.049	0.059	0.059	0.059	0.036		1982	275079	245808	
		2	0.126	0.126	0.126	0.126	0.118	0.118	0.118	0.118	0.128		1983	387631	403890	
		3	0.176	0.176	0.176	0.176	0.142	0.149	0.149	0.149	0.164		1984	428631	450709	
		4	0.211	0.211	0.211	0.211	0.189	0.179	0.179	0.179	0.194					
		5	0.243	0.243	0.243	0.243	0.211	0.217	0.217	0.217	0.211					
		6	0.251	0.251	0.251	0.251	0.222	0.238	0.238	0.238	0.22					
		7	0.267	0.267	0.267	0.267	0.267	0.265	0.265	0.265	0.258					
		8	0.267	0.267	0.267	0.267	0.267	0.265	0.265	0.265	0.258					
	estimated weight		1976	1977	1978	1979	1980	1981	1982	1983	1984					
		0	26715	58855	16620	31304	22849	52684	83823	100029	124575					
		1	61839	20267	44650	12608	23274	43831	70744	112558	81957					
		2	32861	15608	12618	16303	12852	155183	57103	83902	105528					
		3	956	1946	7014	9511	9777	21161	21027	46772	70992					
		4	704	84	46626	727	3693	28238	3868	19549	40639					
		5	37	172	2103	1075	3628	17662	2437	16840	6934					
	Sum		123112	96932	129630	71528	76073	318761	239003	379650	430625					
	sum 0+1+2		121415	94730	73888	60216	58974	251699	211670	296489	312061					
	3+		1908.043	2816.926078	56177.8604	14519.1806	24171.3608	85359.928	34137.4811	107400.8588	138648.51					
	0+1+2+"3+"		123323	97547	130065	74735	83146	337059	245808	403890	450709					



Year	ICES	estimated based on 1982-1984 data and IBTS
1977	46000	97547
1978	11000	130065
1979	25100	74735
1980	70764	83146
1981	174879	337059

Figure 2.11.1 *North Sea herring. Catch data from various sources.*

The use of improved catch data in SP modelling is given in section 2.4.

3 Future meetings

There are no plans for a further meeting in the project group.

4 AOB

No issues was raised.

5 Closing

HS closed the meeting by thanking all the participants for intensive and constructive discussions with a special thank you to John Pope for participating at the entire meeting and making substantial contributions to the discussions. An especially big thank you went to Jeremy for organizing the meeting, venue, hotel, practicalities, etc. so effectively and which resulted in splendid working conditions for us.

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Appendix 1. Agenda and Minutes assignments

ECOSYSTEM Fmsy project

3rd meeting.

Venue: Bay Campus, University of Rhode Island, Kingston, RI 02881, USA

Meeting in Rhode Island, 12-14 March 2018, start at 9:30 the first day and 9:00 the following two days.

Agenda

1. Welcome Monday
2. Adoption of agenda Monday
3. Progress on Work Packages
   a. WP1 **"Common currency" of F** - Henrik S. (minutes Jeremy) Monday
   b. WP2 **Regime shifts, climate changes, genetic changes due to fishing, and suspected misreporting historically** - Petur BB (by Henrik) (minutes Søren) Tuesday
   c. Wp3 **Compile ecosystem and multispecies estimates of Fmsy** – (minutes Claus) Tuesday
      i. Villy
      ii. John Pope and his work on in MAREFRAME and more
   d. WP4 **Surplus production model estimates of Fmsy** (minutes Gunnar) Monday
      i. General – Henrik S.
      ii. Ram Legacy database – Mike
      iii. SPICT runs – Rob + Joe
   e. WP5 **Density dependent growth, maturity and cannibalism** – Jan (Henrik) + Adrien (minutes Villy) Monday
   f. WP6 **Life history parameters relevant for Fmsy** – Henrik Gislasson (minutes Henrik) Tuesday
   g. WP7 **GLM type analysis to "export" ecosystem Fmsy** – Gunnar (minutes Henrik) (short intro Monday) Tuesday
   h. WP8 **Implementation –** Henrik S (minutes Søren) Tuesday
   i. WP11 **Catch data improvements –** Søren/Claus (minutes Jeremy) Tuesday
4. ICCAT perspective on Fmsy estimations – Steve Cadrin Wednesday
5. ICES Theme Session ASC 2018 – Henrik (minutes Claus) Tuesday
6. Symposium program – Henrik Søren Villy (minutes Gunnar) Wednesday
   a. The venue and logistics at DGI BYEN
   b. The tone, panel discussion, invited contributors
   c. Bullit points of presentations
7. Papers – titles and lead authors (minutes Villy) Wednesday

8. Homepage – Henrik S (minutes Søren) Wednesday
9. AOB (minutes Henrik) Wednesday
10. Closing Wednesday

Appendix 2. List of participants.

Participant name	Participant organization name	Country	Short name	Particpated
Henrik Sparholt	Nordic Marine Think Tank (NMTT)	Denmark	HS	Yes
Ray Hilborn	University of Washington	USA	RH	No
Jan Horbowy	National Marine Fisheries Research Institute (NMFRI)	Poland	JH	No
Petur Steingrund	Marine Research Institute, Faroe Islands	Faroe Islands	PS	NO
Jeremy Collie	University of Rhode Island	USA	JC	Yes
Bjarte Bogstad	Institute of Marine Research (IMR)	Norway	BB	No
Daniel Howell	Institute of Marine Research (IMR)	Norway	DH	No
Villy Christensen	University of British Columbia	Canada	VC	Yes
Søren Anker Pedersen	EUFISHMEAL	Denmark	SAP	Yes
Claus Reedtz Sparrevohn	Danish Pelagic Producer Organization	Denmark	CRS	Yes
Rob van Gemert	DTU AQUA	Denmark	RvG	NO
Mike Melnychuk	University of Washington	USA	MM	Yes
Carl Walters	UBC	Canada	CW	NO
Gunnar Stefansson	Univ. of Iceland	Iceland	GS	Yes
Michael Fogarty	National Marine Fisheries Service Ecosystem Assessment Program 166 Water Street Woods Hole,			Yes
John Pope	Independent scientist			Yes
Henrik Gislason	DTU AQUA			No
Steven Cadrin	Department of Fisheries Oceanography. School for Marine Science and Technology. University of Massachusetts Dartmouth.			Yes
Joseph Zottoli	University of Rhode Island	USA		Yes
Adrien Tableau	University of Rhode Island	USA		Yes

Appendix 3. Presentation of RAM Legacy database SP runs.

Fitting post-hoc surplus production models to stock assessment outputs

Mike Melnychuk , Daniel Hively , Ray Hilborn
University of Washington
RAM Legacy Stock Assessment Database

2018-03-12

Usual goals of SP fitting with RAM:

- Cross-validations to compare models and quantify how well ER/ER_{MSY_SP} and TB/TB_{MSY_SP} compare with U/U_{MSY_assess} and B/B_{MSY_assess}

$$\begin{tikzcd} & U \arrow[dl] \arrow[dr] & \\ ER & & F \end{tikzcd} \qquad \begin{tikzcd} & B \arrow[dl] \arrow[dr] & \\ TB & & SSB \end{tikzcd}$$

- Use preferred models to estimate ER/ER_{MSY_SP} and TB/TB_{MSY_SP} for stocks for which assessments do not estimate reference points

General procedure:

1. Calculate annual surplus production from assessment outputs (ΔTB + catch), converting TB from SSB if necessary
2. Fit surplus production models to annual SP values:
   a) 4 alternative shape parameters
   b) 3 alternative biomass types
   c) 2 treatments of B_{MSY} (fixed or freely-varying)
3. Apply series of filters and reject fits failing any filter
4. Using estimated ER_{MSY_SP} , calculate equivalent F_{MSY} in ICES F currency

Surplus production:

Observed:

$SP_{t\_obs} = TB_t - TB_{t-1} + C_t$

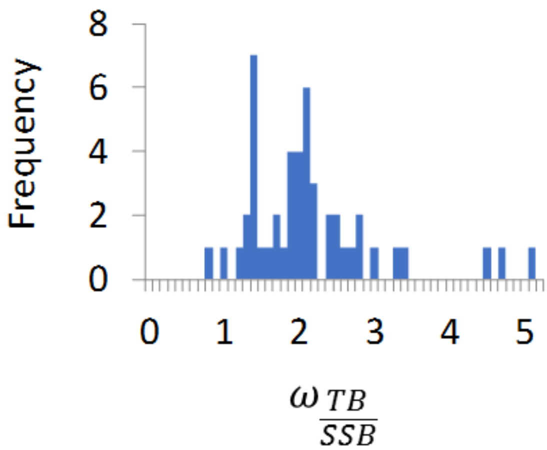
Predicted:

$SP_{t\_pred} =$

$$\left[\left(\frac{\varphi}{\varphi - 1}\right) \cdot B_t \cdot ERMSY\right] - \left[\frac{ER_{MSY} \cdot {B_t}^{\varphi}}{(\varphi - 1) \cdot {B_{MSY}}^{(\varphi - 1)}}\right]$$

Biomass conversions:

$$\omega_{\frac{TB}{SSB}} = \beta_{age} \cdot Age_{SSB} + \\ \beta_M \cdot M + \\ \beta_U \cdot U_{t-1} + \\ \beta_{M:U} \cdot M : U_{t-1} + \\ (1|species)$$



- Fit to observed TB_t / SSB_t
- Defaults to simpler nested models if data missing
- Coefficient estimates specific to ICES stocks

General procedure:

1. Calculate annual surplus production from assessment outputs (ΔTB + catch), converting TB from SSB if necessary

2. Fit surplus production models to annual SP values:

    a) 4 alternative shape parameters

    b) 3 alternative biomass types

    c) 2 treatments of B_{MSY} (fixed or freely-varying)

3. Apply series of filters and reject fits failing any filter

4. Using estimated ER_{MSY_SP} , calculate equivalent F_{MSY} in ICES F currency

Surplus production models:

- Pella-Tomlinson shape parameters:
  - Schaeffer 2
  - Fox 1.00001
  - Thorson meta-analysis, taxa pooled 1.736
  - Thorson meta-analysis, individual taxa
    - Pleuronectiformes 1.406
    - Gadiformes 2.027
    - Perciformes 0.799
    - Clupeiformes 1.427
    - Scorpaeniformes 3.377
    - Other 1.026

Surplus production models:

- Alternative biomass types:
  - SSB
  - TB
  - VB = catch / F

- Alternative treatments of B_{MSY} :
  - freely-varying parameter along with ER_{MSY}
  - Fixed at assessment value of B_{MSY} :
    - SSB_{MSY}
    - TB_{MSY} , converted from SSB_{MSY} if necessary like TB from SSB
    - VB_{MSY} = MSY / F_{MSY} , or else = geometric mean[VB / (SSB / SSB_{MSY})]

General procedure:

1. Calculate annual surplus production from assessment outputs (ΔTB + catch), converting TB from SSB if necessary

2. Fit surplus production models to annual SP values:

    a) 4 alternative shape parameters

    b) 3 alternative biomass types

    c) 2 treatments of B_{MSY} (fixed or freely-varying)

3. Apply series of filters and reject fits failing any filter

4. Using estimated ER_{MSY_SP}, calculate equivalent F_{MSY} in ICES F currency

Filters:

1. number observed SP points > 5
2. More positive than negative SP points in middle quadrants
3. sum of SP points in middle quadrants > 0
4. $ER_{MSY} > 0.005$
5. $0.9 > ER_{MSY}$
6. $B_{MSY} > 0.05 * B_{max}$
7. $2 * B_{max} > B_{MSY}$
8. $f(B_{MSY\_assessment}) > 0$
9. linear fit worse than SP fit

General procedure:

1. Calculate annual surplus production from assessment outputs (ΔTB + catch), converting TB from SSB if necessary

2. Fit surplus production models to annual SP values:

   a) 4 alternative shape parameters

   b) 3 alternative biomass types

   c) 2 treatments of B_{MSY} (fixed or freely-varying)

3. Apply series of filters and reject fits failing any filter

4. Using estimated ER_{MSY_SP} , calculate equivalent F_{MSY} in ICES F-currency

Calculate equivalent F_{MSY} :

$$F_{MSY\_equivalent,\,y} = F_{assess,\,y} / (ER/ER_{MSY})_{SP,\,y}$$

- Calculate arithmetic mean over 2000-2012
- now in ICES F-currency

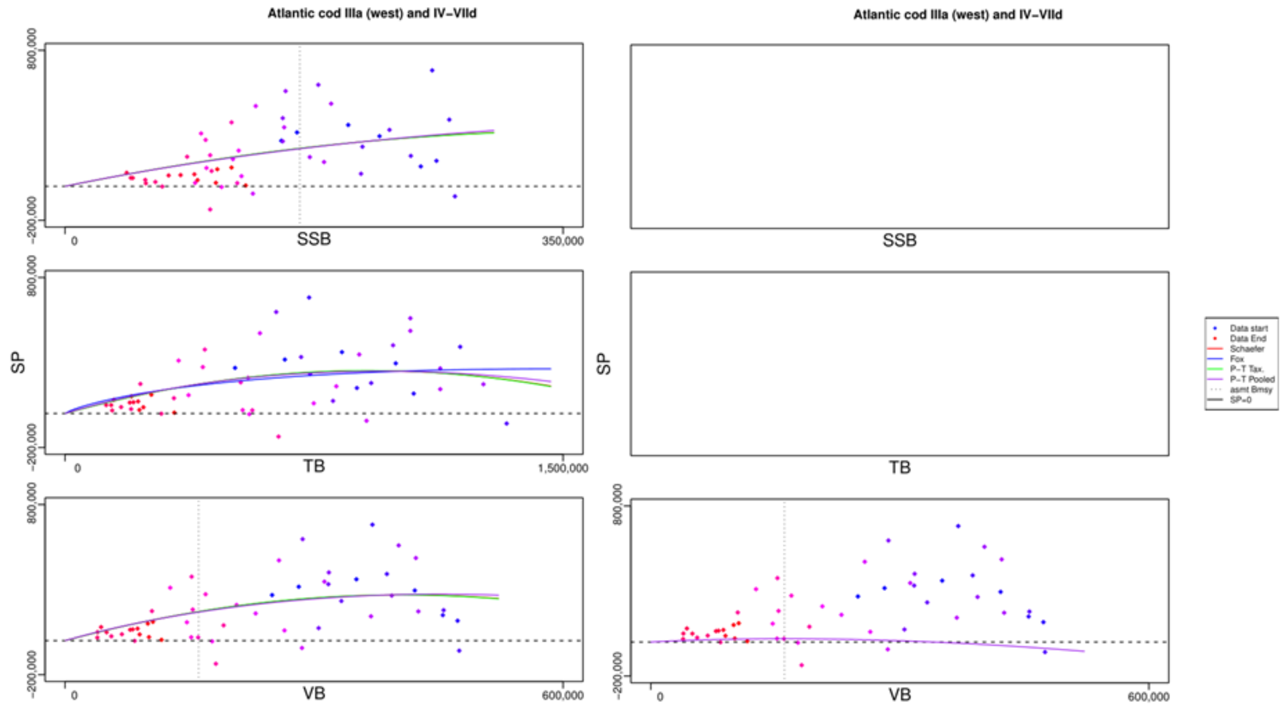
Outputs: "RAM SPmod fits - …"

1. "… full results.csv"
2. "… equivalent Fmsy - …csv" $\begin{bmatrix} B_{MSY}\ fixed \\ B_{MSY}\ free \end{bmatrix}$
3. "… stock tables.pdf"
4. "… stock SP plots - ...pdf"
5. "… stock ts plots - ...pdf"
6. "… scatterplots - ...pdf"

$\begin{bmatrix} B_{MSY}\ fixed \\ B_{MSY}\ free \end{bmatrix}$ X $\begin{bmatrix} passing\ fits \\ all\ fits \end{bmatrix}$

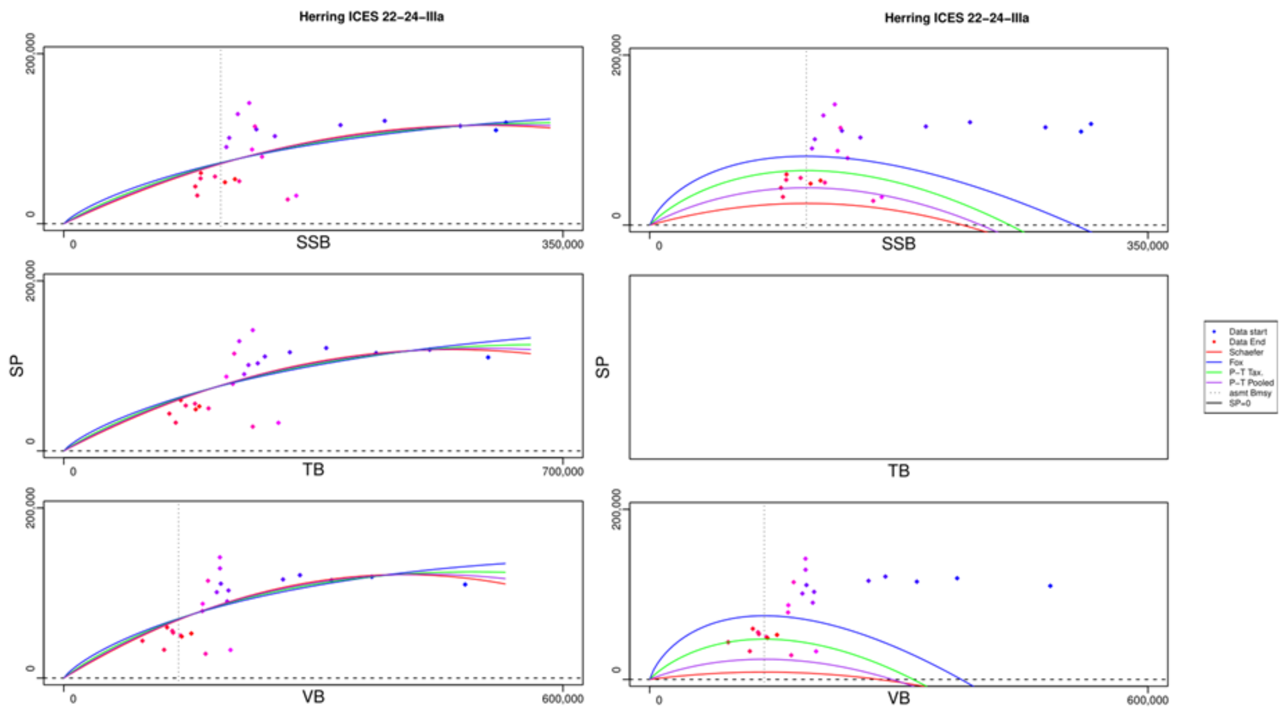
Example SP plots:

B_{MSY} freely-varying B_{MSY} fixed



Example SP plots:

B_{MSY} freely-varying $\qquad$ B_{MSY} fixed



Example stock summary tables:

Atlantic cod IIIa (west) and IV-VIId

Assess ID	WGNSSK-CODIIIaW-IV-VIId-1962-2016-ICESIMP2016
Area ID	multinational-ICES-IIIaW-IV-VIId
TaxGroup	gadids
Scientific Name	Gadus morhua

Assessment values of Uref				
Type	**BRP ID**	**BRP Value**	**gm(U/Uref)**	**final year**
ERmsy				
Fmsy	Fmsy-1/yr	0.33	2.17	2015
ERmgt				
Fmgt	Fmgt-1/yr	0.33	2.17	2015

Model Outputs for free Bmsy									
No.	**Desc.**	**P/F**	**gm(U/Uref)**	**ERmsy**	**eqFmsy**	**Rsq**	**r**	**Δ AICc**	**Failures**
1	b=ssb, p=schaefer	Pass	0.3	0.86	2.44	0.23	0.48	3.79	
2	b=ssb, p=fox	Fail							f7
3	b=ssb, p=pttax	Pass	0.3	0.87	2.46	0.23	0.48	3.77	
4	b=ssb, p=ptpool	Pass	0.34	0.76	2.15	0.23	0.48	3.99	
5	b=tb, p=schaefer	Pass	0.94	0.28	0.78	0.22	0.47	4.77	
6	b=tb, p=fox	Pass	1.42	0.18	0.51	0.19	0.43	6.64	
7	b=tb, p=pttax	Pass	0.93	0.28	0.78	0.22	0.47	4.73	
8	b=tb, p=ptpool	Pass	0.98	0.26	0.74	0.21	0.46	5.19	
9	b=vb, p=schaefer	Pass	0.39	0.66	1.87	0.29	0.54	0.06	
10	b=vb, p=fox	Fail							f7
11	b=vb, p=pttax	Pass	0.39	0.66	1.88	0.29	0.54	0	
12	b=vb, p=ptpool	Pass	0.43	0.61	1.72	0.28	0.53	0.6	

Model Outputs for fixed Bmsy									
No.	**Desc.**	**P/F**	**gm(U/Uref)**	**ERmsy**	**eqFmsy**	**Rsq**	**r**	**Δ AICc**	**Failures**
13	b=ssb, p=schaefer	Fail							f5
14	b=ssb, p=fox	Fail							f5
15	b=ssb, p=pttax	Fail							f5
16	b=ssb, p=ptpool	Fail							f5
17	b=tb, p=schaefer								
18	b=tb, p=fox								
19	b=tb, p=pttax								
20	b=tb, p=ptpool								
21	b=vb, p=schaefer	Fail							f4
22	b=vb, p=fox	Fail							f5
23	b=vb, p=pttax	Fail							f4
24	b=vb, p=ptpool	Pass	2.15	0.12	0.34	0.06	-0.25	0	

Example stock summary tables:

Herring ICES 22-24-IIIa

Assess ID	HAWG-HERR2224IIIa-1991-2016-ICESIMP2016
Area ID	multinational-ICES-22-24-IIIa
TaxGroup	forage fish
Scientific Name	Clupea harengus

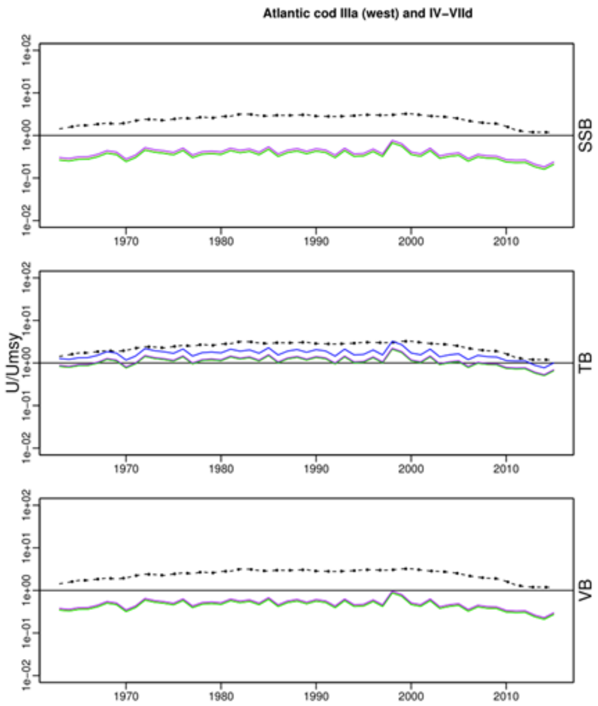
Assessment values of Uref				
Type	**BRP ID**	**BRP Value**	**gm(U/Uref)**	**final year**
ERmsy				
Fmsy	Fmsy-1/yr	0.32	1.44	2015
ERmgt				
Fmgt	Fmgt-1/yr	0.32	1.44	2015

Model Outputs for free Bmsy									
No.	**Desc.**	**P/F**	**gm(U/Uref)**	**ERmsy**	**eqFmsy**	**Rsq**	**r**	**△ AICc**	**Failures**
1	b=ssb, p=schaefer	Pass	0.83	0.39	0.55	0.27	0.52	6.86	
2	b=ssb, p=fox	Pass	1.28	0.26	0.36	0.26	0.51	7.17	
3	b=ssb, p=pttax	Pass	0.97	0.34	0.48	0.27	0.52	6.98	
4	b=ssb, p=ptpool	Pass	0.88	0.37	0.52	0.27	0.52	6.9	
5	b=tb, p=schaefer	Pass	1.5	0.22	0.31	0.42	0.65	1.96	
6	b=tb, p=fox	Pass	2.49	0.13	0.19	0.38	0.61	3.42	
7	b=tb, p=pttax	Pass	1.78	0.18	0.26	0.4	0.63	2.7	
8	b=tb, p=ptpool	Pass	1.6	0.21	0.29	0.41	0.64	2.27	
9	b=vb, p=schaefer	Pass	1.1	0.3	0.42	0.47	0.69	0	
10	b=vb, p=fox	Pass	1.76	0.19	0.26	0.41	0.64	2.14	
11	b=vb, p=pttax	Pass	1.29	0.25	0.36	0.45	0.67	1.1	
12	b=vb, p=ptpool	Pass	1.17	0.28	0.4	0.46	0.68	0.46	

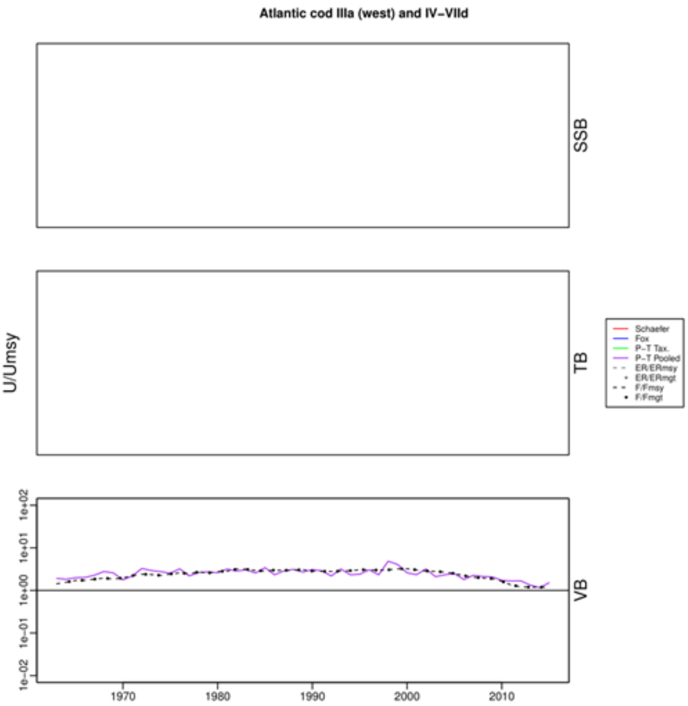
Model Outputs for fixed Bmsy									
No.	**Desc.**	**P/F**	**gm(U/Uref)**	**ERmsy**	**eqFmsy**	**Rsq**	**r**	**△ AICc**	**Failures**
13	b=ssb, p=schaefer	Pass	1.42	0.23	0.33	0.16	-0.4	22.48	
14	b=ssb, p=fox	Pass	0.45	0.74	1.04	0.16	-0.4	0	
15	b=ssb, p=pttax	Pass	0.56	0.58	0.82	0.16	-0.4	11.95	
16	b=ssb, p=ptpool	Pass	0.82	0.4	0.56	0.16	-0.4	18.75	
17	b=tb, p=schaefer								
18	b=tb, p=fox								
19	b=tb, p=pttax								
20	b=tb, p=ptpool								
21	b=vb, p=schaefer	Pass	5.25	0.06	0.09	0.13	-0.36	24.49	
22	b=vb, p=fox	Pass	0.61	0.54	0.76	0.15	-0.39	5.27	
23	b=vb, p=pttax	Pass	0.96	0.34	0.48	0.14	-0.38	17.49	
24	b=vb, p=ptpool	Pass	1.91	0.17	0.24	0.14	-0.37	22.59	

Example time series plots:

B_{MSY} freely-varying

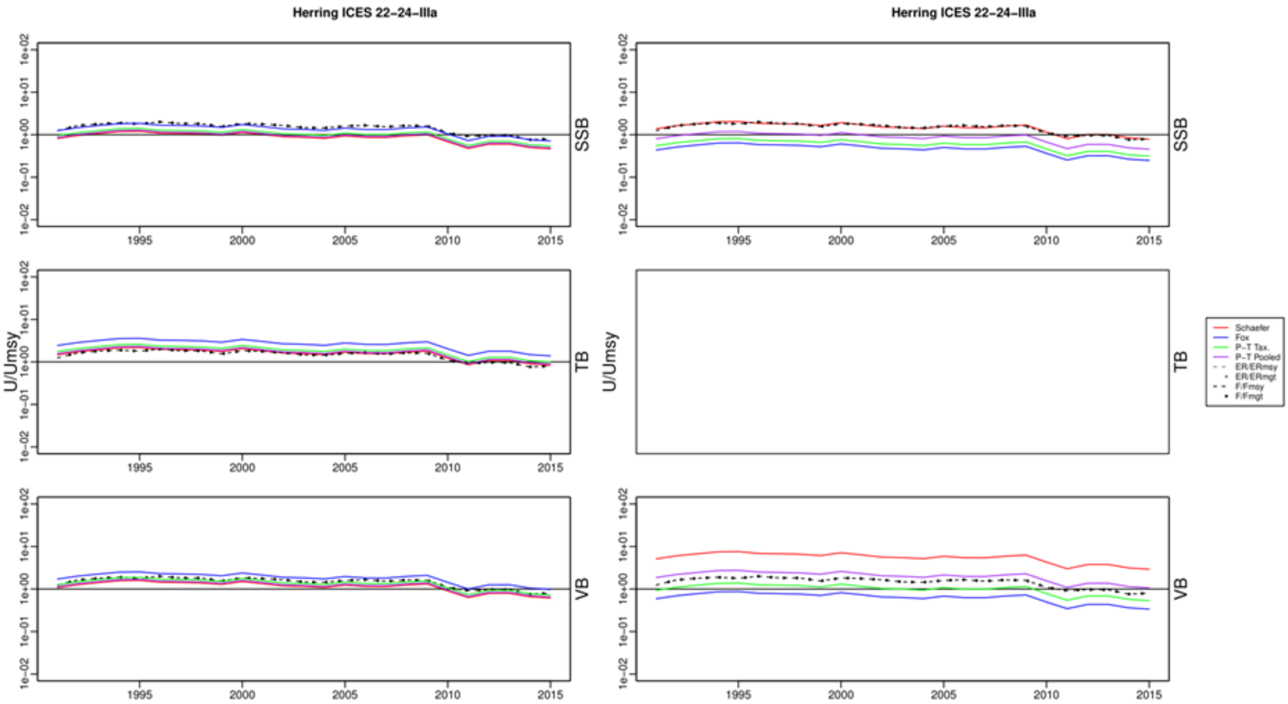


B_{MSY} fixed



Example time series plots:

B_{MSY} freely-varying　　　　B_{MSY} fixed



Model fits passing all 9 filters

	B_{MSY} free		B_{MSY} fixed	
model	n	% passed	n	% passed
SSB ; Schaefer	71	80%	64	72%
SSB ; Fox	71	69%	64	75%
SSB ; P-T (Taxon)	71	77%	64	72%
SSB ; P-T (Pooled)	71	77%	64	73%
TB ; Schaefer	75	85%	18	78%
TB ; Fox	75	76%	18	89%
TB ; P-T (Taxon)	75	83%	18	83%
TB ; P-T (Pooled)	75	83%	18	83%
VB ; Schaefer	69	86%	64	61%
VB ; Fox	69	71%	64	88%
VB ; P-T (Taxon)	69	77%	64	67%
VB ; P-T (Pooled)	69	86%	64	70%

% error between SP_{pred} and SP_{obs} for the 34 LCD stocks with free B_{MSY} passing all filters

	B_{MSY} free		B_{MSY} fixed	
model	n	mean % error	n	mean % error
SSB ; Schaefer	34	0.5%	23	-0.6%
SSB ; Fox	34	0.5%	24	-0.1%
SSB ; P-T (Taxon)	34	0.4%	23	-0.5%
SSB ; P-T (Pooled)	34	0.5%	23	-0.5%
TB ; Schaefer	34	0.6%	3	-0.8%
TB ; Fox	34	0.6%	4	1.0%
TB ; P-T (Taxon)	34	0.6%	3	-0.3%
TB ; P-T (Pooled)	34	0.6%	3	-0.7%
VB ; Schaefer	34	0.5%	20	-0.5%
VB ; Fox	34	0.5%	29	0.1%
VB ; P-T (Taxon)	34	0.5%	23	-0.3%
VB ; P-T (Pooled)	34	0.5%	24	-0.4%

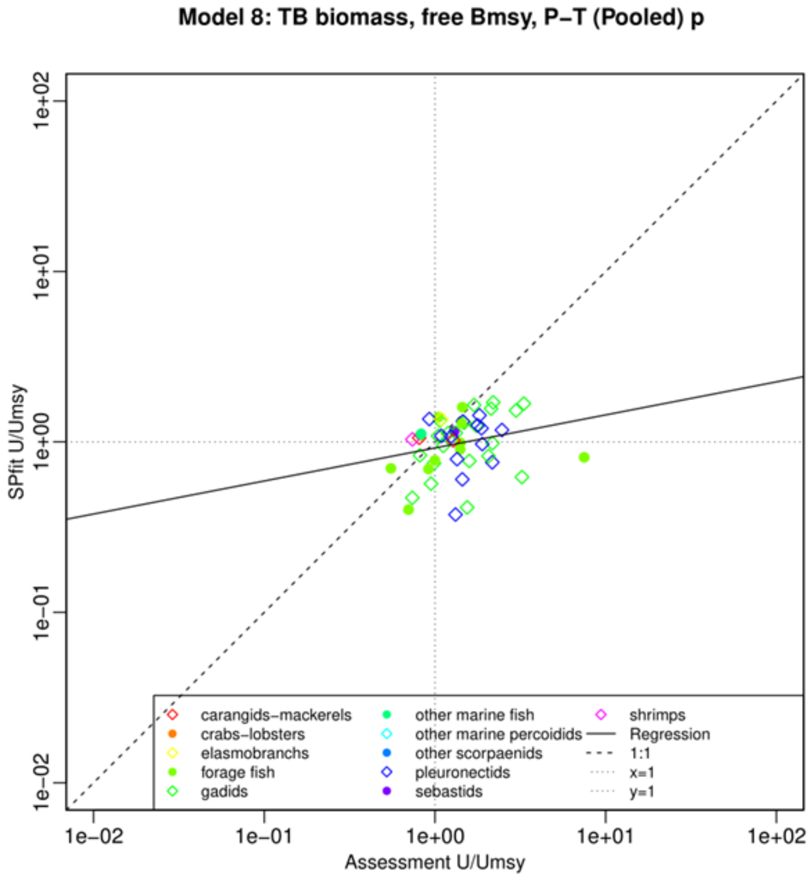
Correlations of SP_{pred} and SP_{obs} for the 34 LCD stocks with free B_{MSY} passing all filters

	B_{MSY} free		B_{MSY} fixed	
model	n	mean *r*	n	mean *r*
SSB ; Schaefer	34	0.22	23	0.00
SSB ; Fox	34	0.23	24	0.00
SSB ; P-T (Taxon)	34	0.23	23	0.00
SSB ; P-T (Pooled)	34	0.22	23	0.00
TB ; Schaefer	34	0.30	3	-0.09
TB ; Fox	34	0.31	4	-0.10
TB ; P-T (Taxon)	34	0.31	3	-0.09
TB ; P-T (Pooled)	34	0.31	3	-0.09
VB ; Schaefer	34	0.25	20	-0.05
VB ; Fox	34	0.27	29	-0.06
VB ; P-T (Taxon)	34	0.26	23	-0.05
VB ; P-T (Pooled)	34	0.26	24	-0.06

ΔAICc between SP_{pred} and SP_{obs} for the 34 LCD stocks with free B_{MSY} passing all filters

	B_{MSY} free		B_{MSY} fixed	
model	n	mean ΔAICc	n	mean ΔAICc
SSB ; Schaefer	34	6.4	23	24.0
SSB ; Fox	34	4.5	24	2.2
SSB ; P-T (Taxon)	34	6.1	23	19.5
SSB ; P-T (Pooled)	34	5.9	23	20.0
TB ; Schaefer	34	2.4	3	33.6
TB ; Fox	34	2.6	4	0.4
TB ; P-T (Taxon)	34	2.4	3	15.8
TB ; P-T (Pooled)	34	2.4	3	27.2
VB ; Schaefer	34	3.7	20	27.8
VB ; Fox	34	2.9	29	4.2
VB ; P-T (Taxon)	34	3.6	23	17.3
VB ; P-T (Pooled)	34	3.4	24	20.1

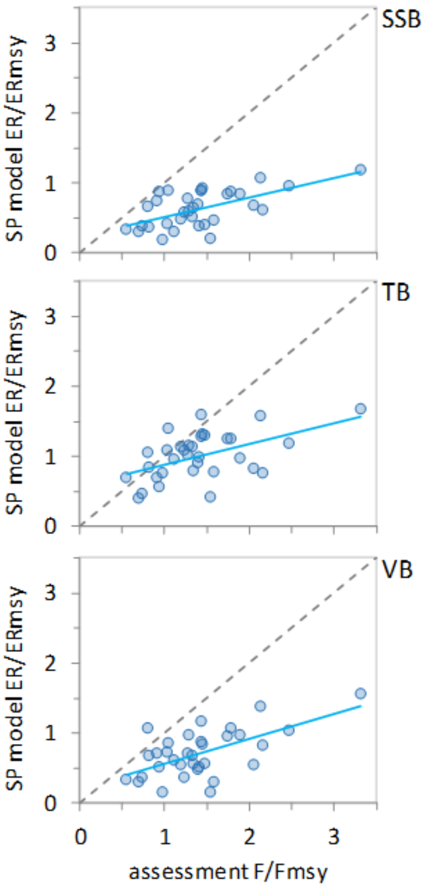
Mean ER/ER$_{MSY_SP}$ versus mean F/F$_{MSY_assess}$



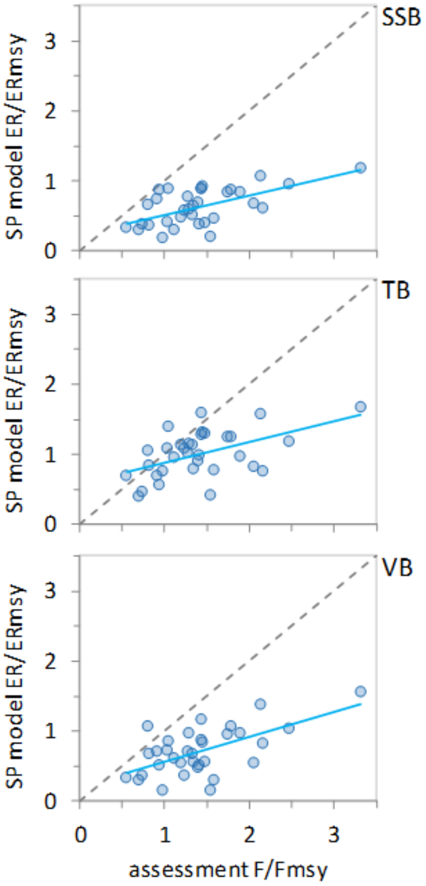
Sensitivity of ER_{MSY_SP} and $F_{MSY\_equivalent}$ to model assumptions

- Generally more variability due to selection of biomass type (SSB ; TB ; VB) than to shape parameter assumed

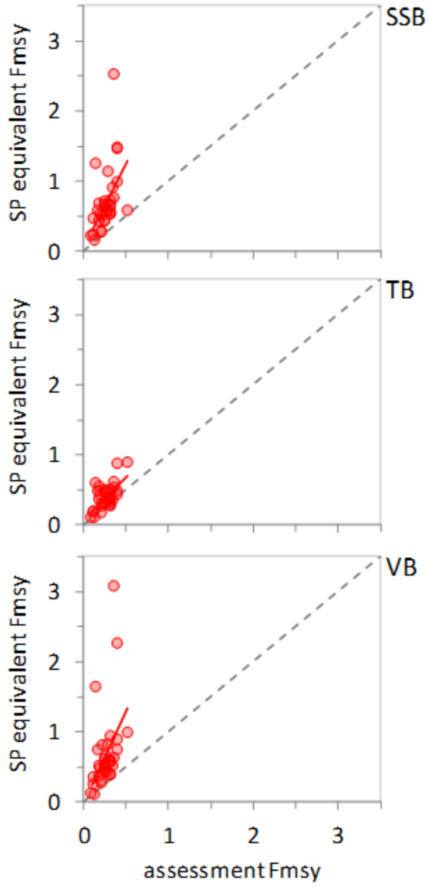
- Does sensitivity in estimated ER_{MSY_SP} disappear after:
  - Use in ratios, ER/ER_{MSY_SP} ? (no)
  - Conversion to $F_{MSY\_equivalent}$? (no)

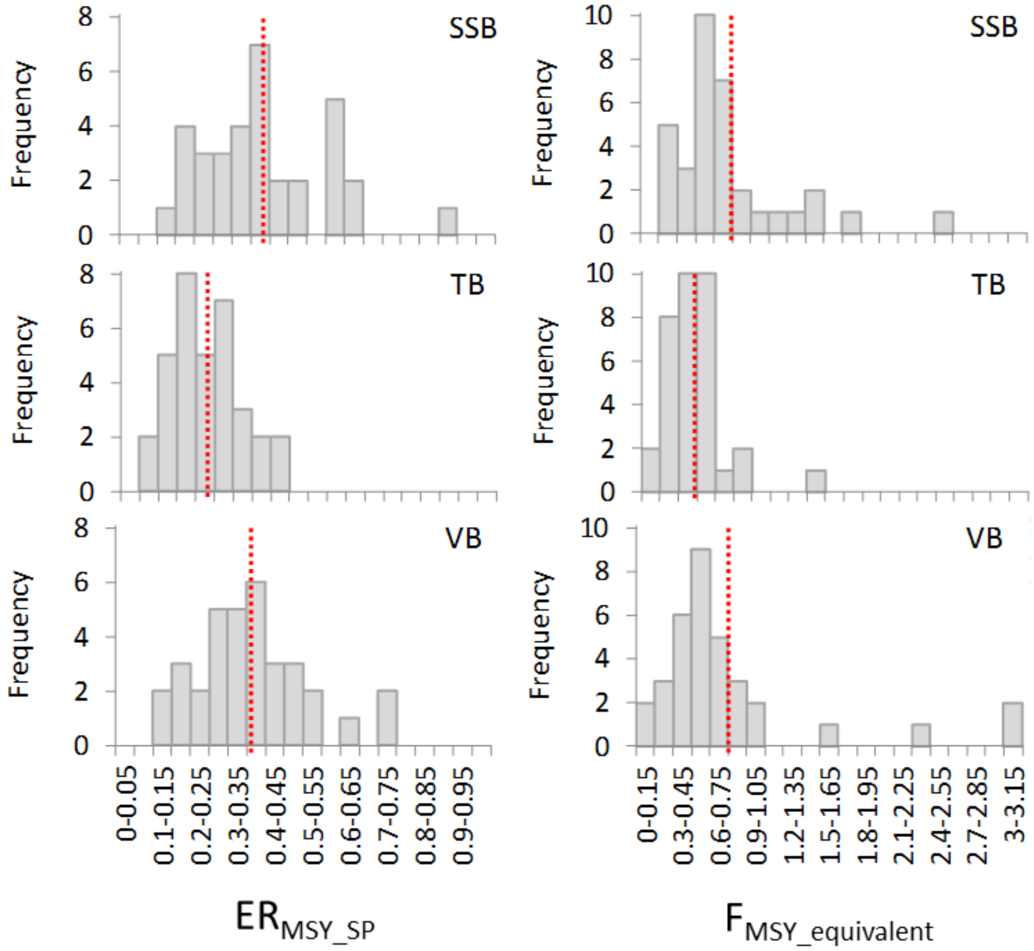


Mean ER/ER_{MSY_SP}
0.64
1.01
0.70

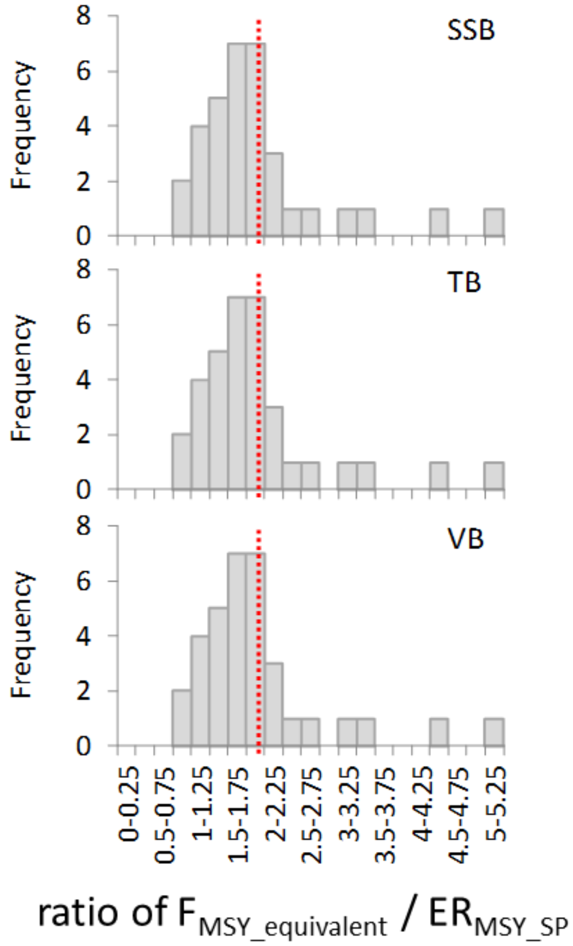


Mean ER/ER_{MSY_SP}	Mean $F_{MSY\_equivalent}$
0.64	0.73
1.01	0.43
0.70	0.76





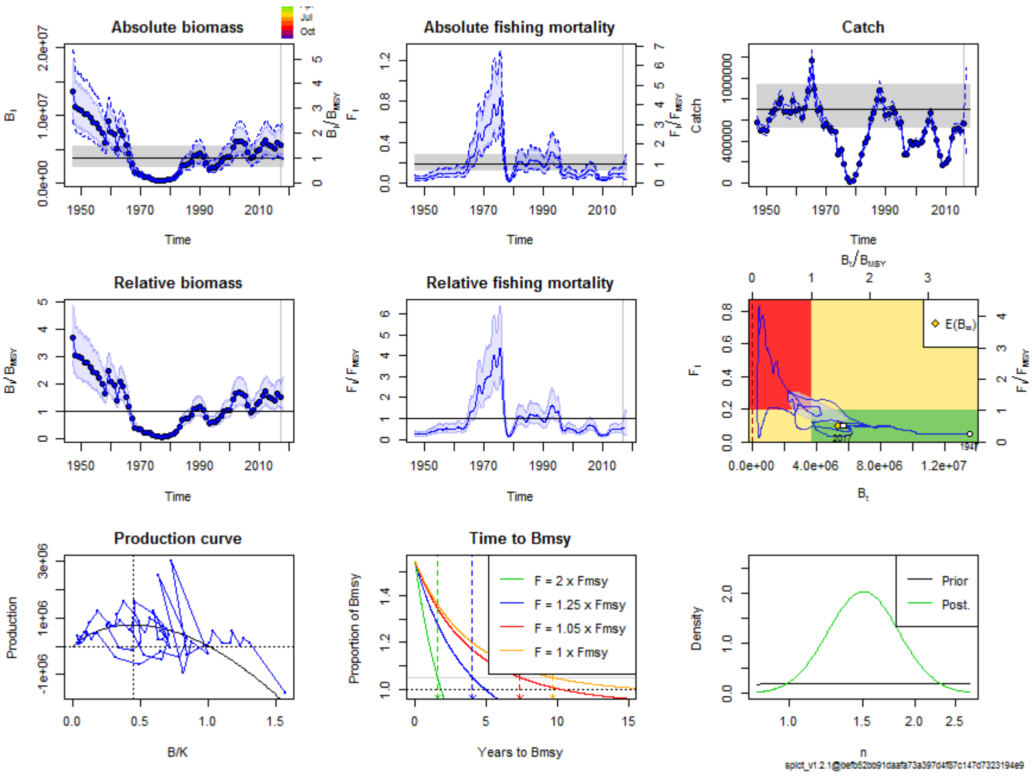
SSB
TB
VB
Frequency
0-0.05
0.1-0.15
0.2-0.25
0.3-0.35
0.4-0.45
0.5-0.55
0.6-0.65
0.7-0.75
0.8-0.85
0.9-0.95
0-0.15
0.3-0.45
0.6-0.75
0.9-1.05
1.2-1.35
1.5-1.65
1.8-1.95
2.1-2.25
2.4-2.55
2.7-2.85
3-3.15
ER_{MSY_SP}
$F_{MSY\_equivalent}$

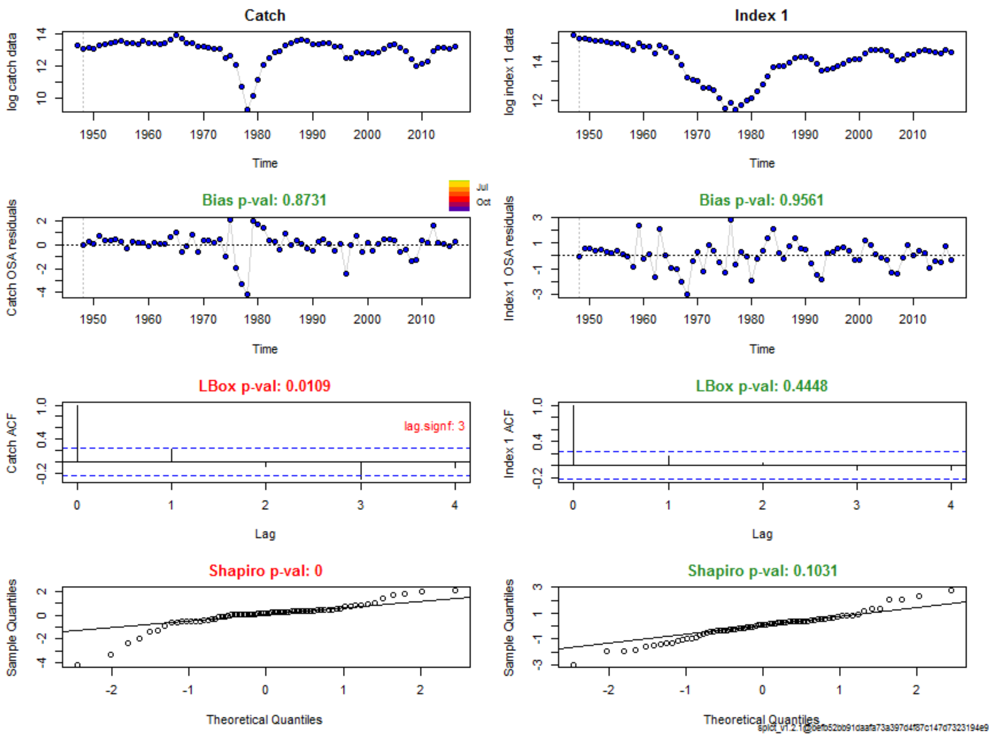


Ratio of $F_{MSY\_equivalent}$ / ER_{MSY_SP} is identical across biomass types because ER depends on biomass type just like ER_{MSY_SP} does

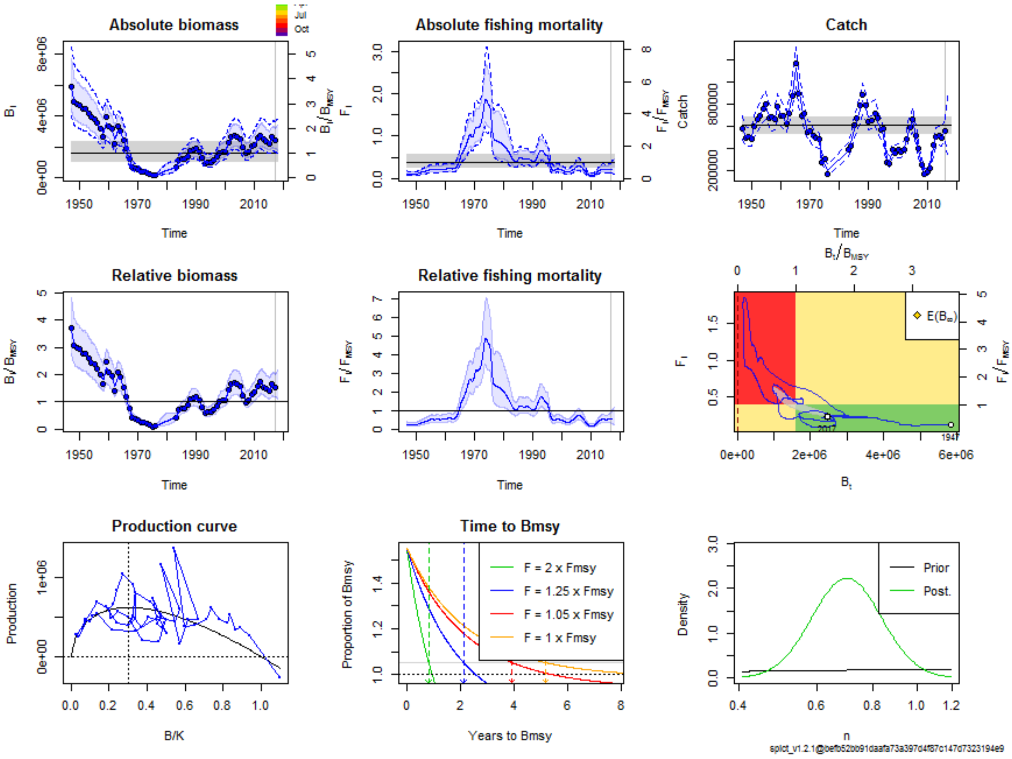
Appendix 4. SPiCT results North Sea herring

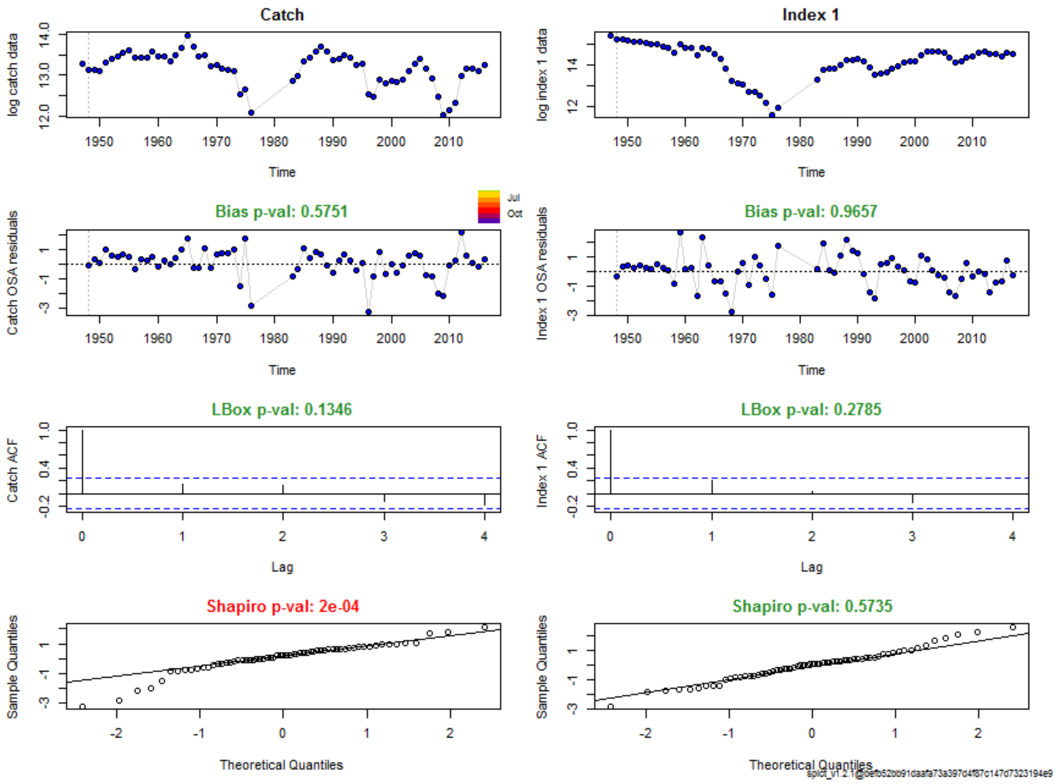
Uncorrected time series. Biomass index: SSB. Start timeseries: 1947.



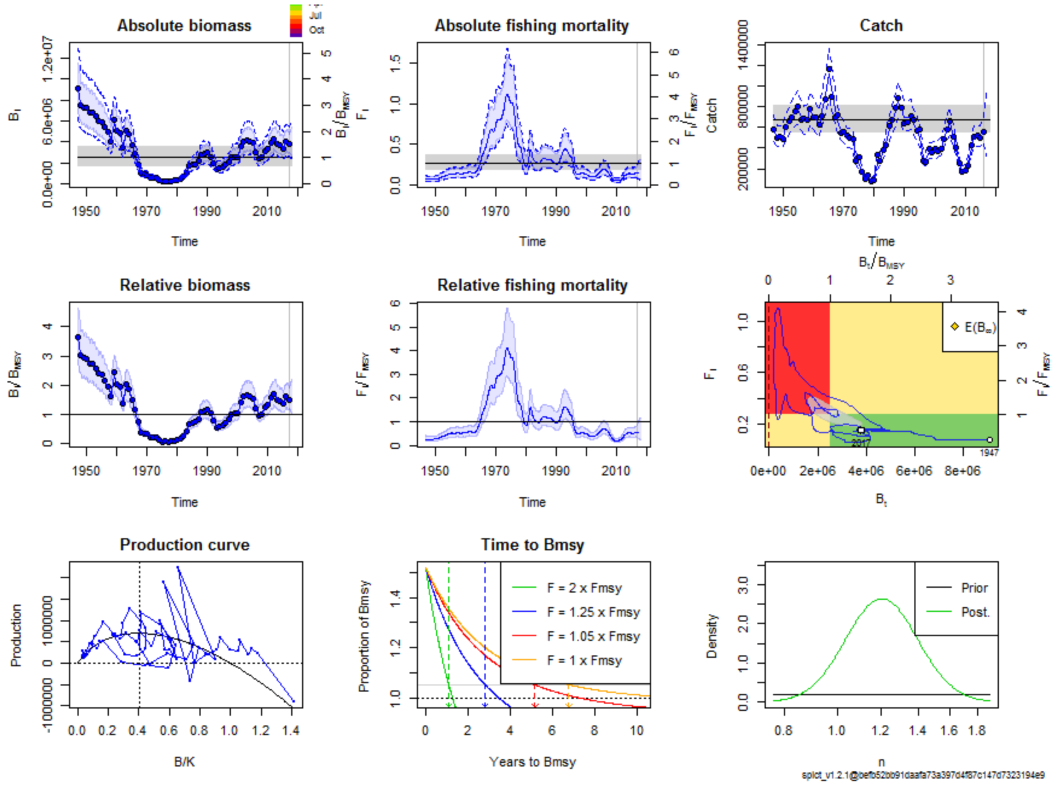


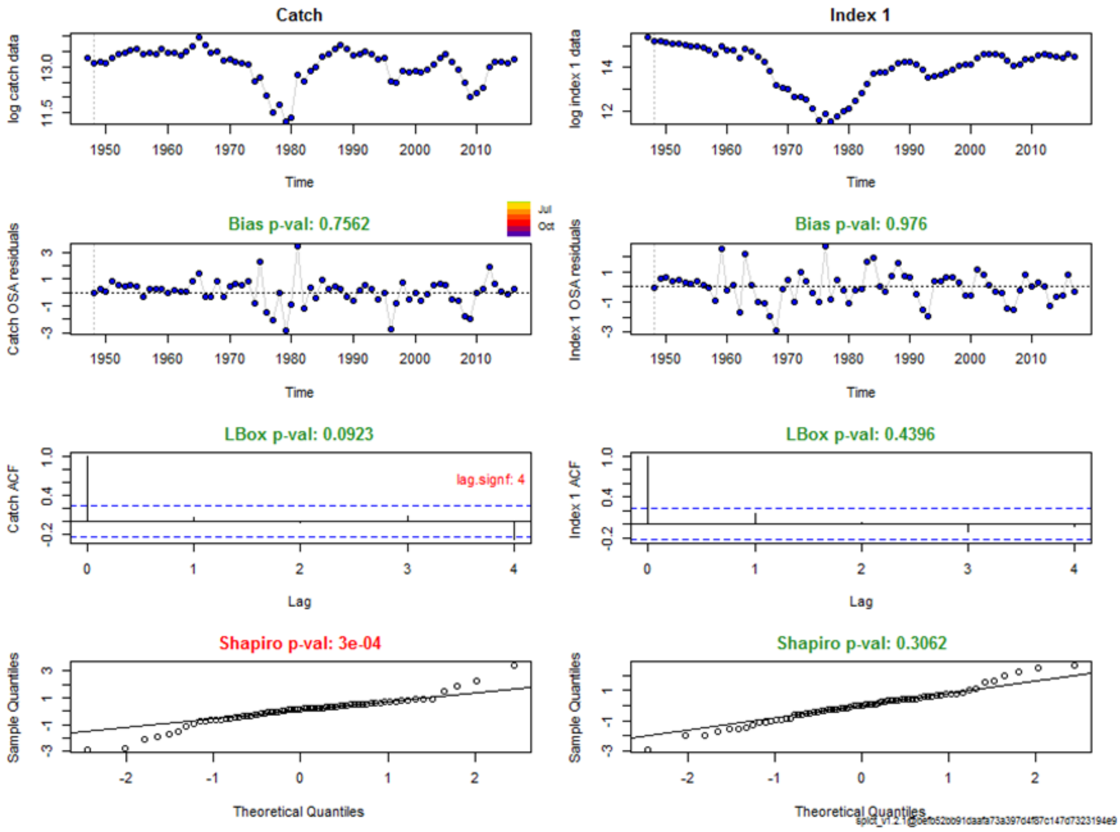
Time series corrected for misreporting by removing years 1977-1982. Biomass index: SSB. Start timeseries: 1947.



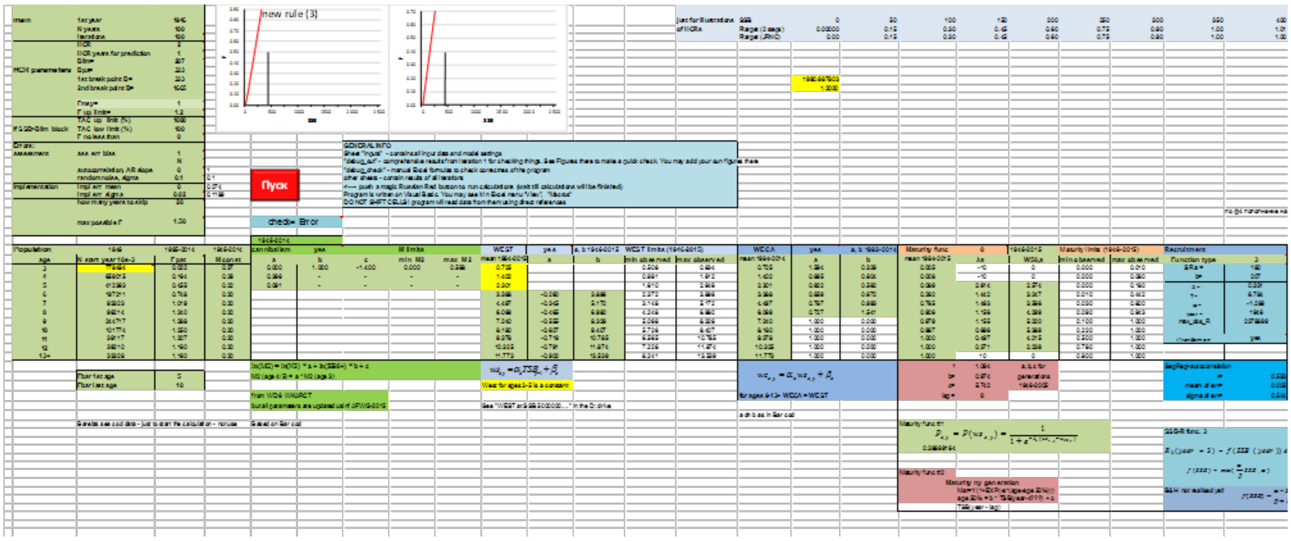


Time series corrected for misreporting by estimating catch data in misreported years from the catch numbers to IBTS CPUE ratio from 1982-1984. Biomass index: SSB. Start timeseries: 1947.




Catch
Index 1
log catch data
log index 1 data
Time
Bias p-val: 0.7562
Bias p-val: 0.976
Jul
Oct
Catch OSA residuals
Index 1 OSA residuals
LBox p-val: 0.0923
LBox p-val: 0.4396
lag.signf: 4
Catch ACF
Index 1 ACF
Lag
Shapiro p-val: 3e-04
Shapiro p-val: 0.3062
Sample Quantiles
Theoretical Quantiles

Appendix 5. Input to Fmsy calculation of Cod Iceland.



Appendix 6 WP11 Catch data improvements

Background

At the Vancouver meeting (31 October-2 November 2017) we agreed to focus on the following stocks:

- Cod North Sea
- Cod NEArctic
- Herring North Sea
- Plaice North Sea
- Mackerel NE Atlantic
- (Haddock North Sea)

Mis-reporting, discarding, and high-grading have been reported for these stocks. Furthermore, there are relatively good information on what might have happened historically.

International Council for the Exploration of the Seas (ICES) assessment working group (ICES WG) catch data are the default data to be used in the present project because these are linked specifically to stocks and some un-reported catches are included, when relatively solid information about it are available. The aim of WP11 is to further improve the ICES WG data if possible. Pauly and Zeller (2015) – a "Sea Around Us" product - is an important source of information for this.

The Sea Around Us catch data reconstruction project use public available electronic landings data from the ICES as a 'reporting' baseline for their reconstruction. This baseline is then improved upon using all data accessible, including ICES stock assessments, peer-reviewed literature, grey literature and local expert opinions. Illegal, Unreported and Unregulated (IUU) catches are assessed in the form of unreported catch, over-reported catch, discarded by catch, as well as recreational and subsistence catches.

Historical catch data are very important for the results of the present project. Therefore, biases, mis-reporting, discards, and related issues will be scrutinized with the aim of correcting the time series. Issues that were sensitive decades ago, might now be possible to treat objectively and scientifically. Conversion factors for gutted fish to whole fish, overfilling fish boxes to be on the "safe" side in relation to quota management and the like, might have biased the current time series. There have been attempts in the scientific literature to correct for such things by e.g. ICES and the "Sea Around Us" project. Such sources of information will be evaluated. There will be a focus on a limited number of case studies in order to show the magnitude of influence on the obtained Fmsy reference point estimates by the project.

This working document gives a presentation and evaluation of the catch data for the above stocks for the agreed timeseries 1950-2016. Three catch data time series are compared:

1) The official catch data 1950-2010 from FAO/EUROSTAT/ICES database - ICES 2011, Copenhagen. Data can be downloaded from the ICES webpage: click here

2) Reconstructed catch data from the Sea Around Us reconstruction project. A full description is given at the Sea Around Us project webpage where the data are available for download: click here
3) The catch data used in the ICES assessment groups. Data can be downloaded from the ICES webpage: click here
4)

North Sea cod

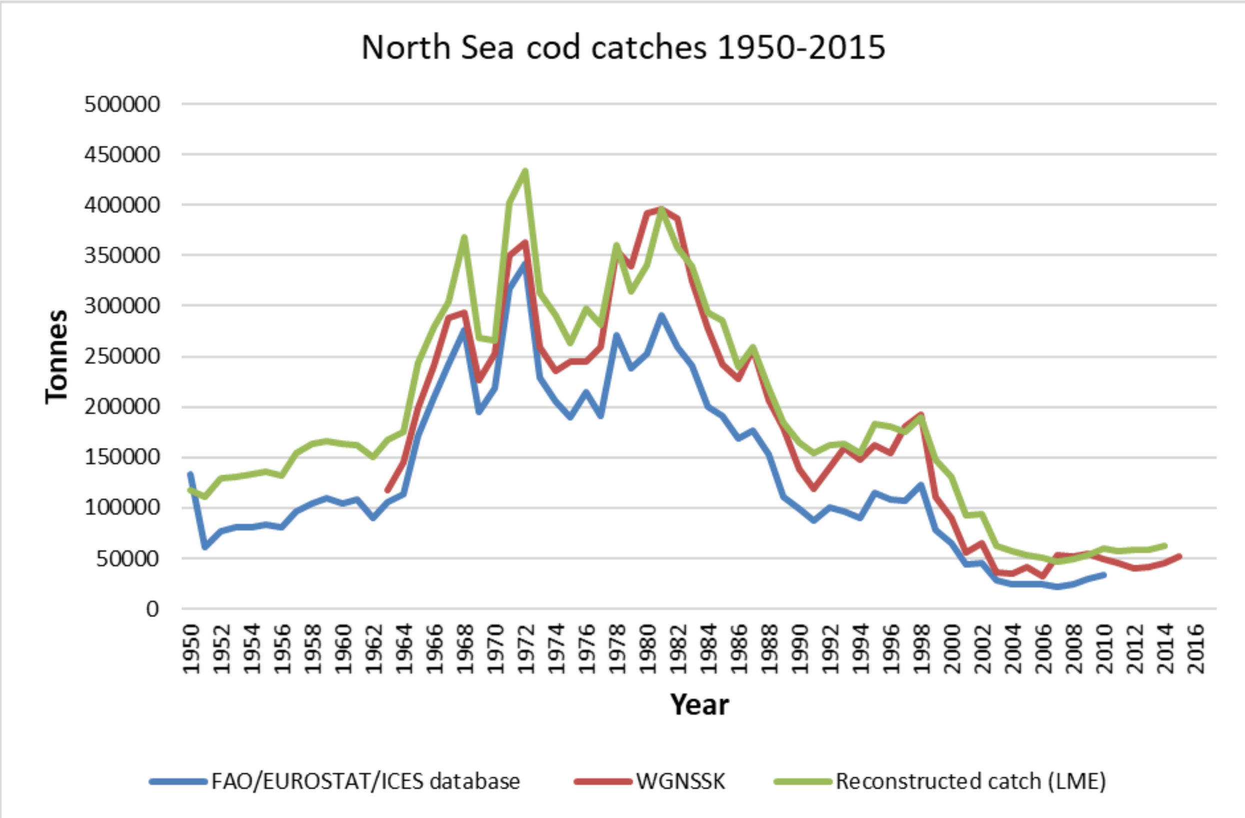


Figure 1. North Sea cod catches 1950-2015. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), **Reconstructed catch data from the Sea Around Us reconstruction project (green line)**, **and the catch data used by the ICES assessment group (red line). Data in Annex 1.**

Reconstructed catch data from the Sea Around Us project

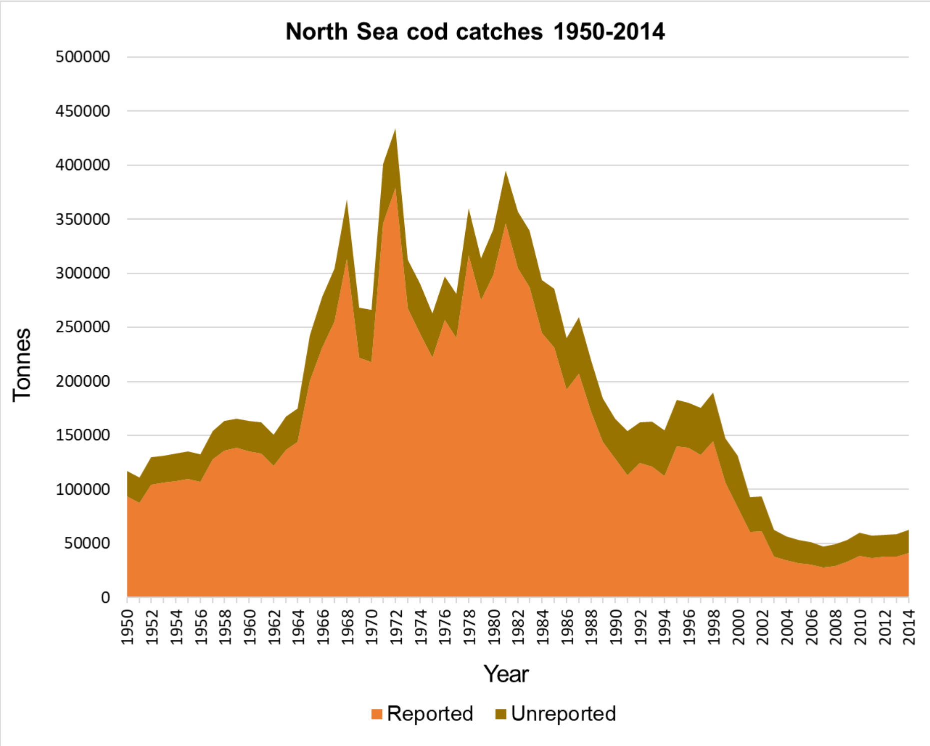


Figure 2. North Sea cod reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

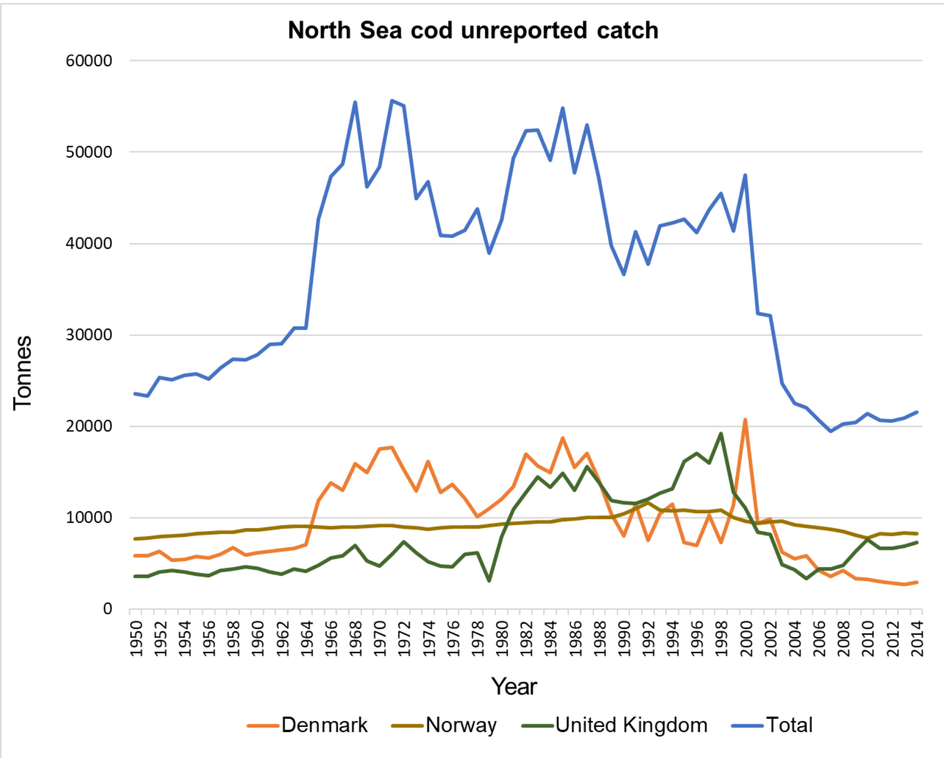


Figure 3. North Sea cod unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project.

Denmark

Landings data (Reported catch)
Gibson et al. (2014) use Denmark's landing values provided by ICES as a baseline for the entire time series from 1950-2010.

Illegal, Unreported and Unregulated catches (Unreported catch)
Unreported landings
According to Gibson et al. (2014) ICES provides annual stock assessments (ICES 2002, 2003, 2012a, 2012b, 2012c, 2012e) in which they evaluate stocks of commercially important taxa in the northern Atlantic Ocean, the North Sea and the Baltic Sea. ICES stock assessments also report on estimates of so-called 'unallocated' catch (euphemism for 'unreported catches' and not assigned to a fishing country) provided as a total for all countries fishing a specific stock in a specific year. In order to estimate Denmark's portion of this unreported catch with the data and information accessible. Gibson et al. (2014) assume proportionality between the reported landings by country and the 'unallocated' catches as presented in the stock assessment reports. Thus, they make the simplifying assumption that all fishing countries misreport in proportion to their reported landings, which clearly may not hold for all countries. Unfortunately, such simplifying assumptions of equal country treatment are necessary until ICES and its member countries comprehensively declare the origin of all catches (Gibson et al., 2014).

The unreported catches vary substantially over time, and no data are available before the 1980s for most taxa for Denmark. Gibson et al. (2014) calculate a rate of unreported catch as a percentage (unreported/landing+unreported) for the first year with available data for each taxon (Table 1). An assumed anchor point of 5% of unreported catch was assigned in 1950 for each taxon. The rate of unreported catch was interpolated between the first year of landed catch and the stock assessment anchor point. These rates were then applied to landings from corresponding years and taxa. If the anchor point rate from ICES stock assessments is less than 5%, that rate was carried back to 1950.

Table 1. Anchor points used to estimate the unreported landings of commercially important taxa in Denmark based on ICES stock assessment reports 1950-2010.

Taxon	ICES area	Assumed 1950 percentage of unreported landings	First year with available data	Anchor point from stock assessment (%)
European plaice	IIIa	1.1	1972	1.1
European plaice	IVb	5.0	1980	27.1
Common sole	IVb	0.5	1982	0.5
Saithe	IIIa	3.6	1990	3.5
Saithe	IVb	3.6	1990	3.6
Whiting	IVb	1.4	1993	1.4
Haddock	IVb	5.0	1992	27.6
Atlantic cod	IIIa	3.4	2002	3.4
Atlantic cod	IVb	5.0	1993	9.7
Atlantic mackerel	IIIa	5.0	1986	8.3
Atlantic mackerel	IVb	5.0	1986	8.3
Altantic horse mackerel	IIIa	5.0	1989	5.0
Atlantic horse mackerel	IVb	5.0	1989	5.0
Atlantic herring	IVb	5.0	2002	21.8

Negative adjustments
Some 'unallocated' values in the ICES stock assessments are negative and represent over-reporting for the year. Gibson et al. (2014) assume the same proportionality as for unreported catches. For Denmark's proportion of over-reported values, these catches are subtracted from the ICES baseline data. Just as for

unreported catches, these adjustments are inconsistent and are not available before the 1980s, therefore Gibson et al. (2014) did not interpolate back to 1950 for any negative adjustments.

Discards

ICES provides some estimates of discards in their stock assessment reports, and presents these estimates similar to 'unallocated' catches. For example, discards are estimated as a tonnage of herring discards as a result of targeting herring for all European countries targeting the species in a specific area. Gibson et al. (2014) assume proportionality between Denmark's portion of the total European reported catch and Denmark's portion of European discards. For each taxon, an average discard rate is taken from the first three years of available data. Gibson et al. (2014) then apply the average discard rate to past catches with no available discard information. This creates discard tonnages for the entire time series 1950-2010. It is understood that changes in effort, quotas and gear restrictions over time may alter the rate of discarding. This may lead to a misreporting of Denmark's discards; however, provides the best possible estimation, since much of this information acquired by DTU is not publically available (Gibson et al., 2014). This method of estimation is used for Atlantic herring, haddock, whiting, European plaice, Atlantic mackerel (*Scomber scombrus*) and Northern shrimp (*Pandalus borealis*). These taxa contribute approximately 22% to the total catch for Denmark. In order to estimate discards of other important taxa, Gibson et al. (2014) rely on data from Denmark's observer program.

Gibson et al. (2014) believe that discard rates of some taxa presented in the DTU observer program report (Storr-Paulsen *et al.* 2010) may be higher than actual overall rates. Gibson et al. (2014) believe this discrepancy is a result of the lack of observer coverage on pelagic and industrial fishmeal vessels. In order to deal with this issue, Gibson et al. (2014) have decided to use discard rates from the German North Sea fisheries as a proxy for Atlantic cod and American plaice (*Hippoglossoides platessoides*). They recognize that this may add uncertainty; however the two countries both operate under the European Commission's Common Fisheries Policy (CFP), and both fish within ICES division IVb. Therefore, each country operates under the same quota regulations with similar species distributions in their waters, and similar types of vessels.

Recreational catch

The European Commission's CFP requested member states to begin monitoring and estimating the catches of recreational fisheries in 2008 (Gibson et al., 2014). As a result, Denmark began to estimate catches of Atlantic cod and European eel using a recall survey in 2009 (Gibson et al., 2014). Sea trout was added to the survey in 2010 (Sparrevohn and Storr-Paulsen 2012a,b). DTU Aqua reports provide catch values as well as catch and release numbers for these species since 2009 for various bodies of water surrounding Denmark. Gibson et al. (2014) recreational catch anchor points estimated from these reports include both passive gear and angling catches, as well as DTUs estimate of illegal catches from Kattegat, Skagerrak, the North Sea and Limfjorden (Table 2). Data for cod in 2009 and 2010 are averaged to avoid an unrealistic spike in 2010 recreational catches. The average is used as anchor points for both 2009 and 2010. An ICES report on recreational fishing surveys was used as confirmation for cod and eel catches (ICES 2012).

Table 2. Anchor points to estimate recreational catches (in tonnes) from 1950-2010. Dashed line (-) indicates years in which linear interpolations were used.

Year	Atlantic cod	Sea trout	European eel	Garfish	European plaice	European flounder	Common dab	Atlantic bluefin tuna
1950	463	0	195	0	77	77	77	-
1959	-	-	-	-	-	-	-	0.3
1964	-	-	-	-	-	-	-	0.0
1970	926	-	-	-	154	154	154	-
1992	-	167	-	167	-	-	-	-
2009	545	-	39	-	91	91	91	-
2010	545	167	43	167	91	91	91	-

Subsistence catch

Recreational fishing occurs with the intention of pleasure regardless of whether the catch is consumed or not. Subsistence fishing, however, is primarily driven by fishing for consumption by fishers and their families. Clearly, over time, these two components have overlapped and replaced each other in Europe. Fishing for flatfish on the western coast of Jutland occurred after World War II in small amounts. Gibson et al. (2014) assume that there was a small amount of subsistence fishing in the rural regions of Jutland during the early time period, and they assume that 'subsistence' *per se* ended by the 1970s. Therefore, Gibson et al. (2014) arbitrarily select an anchor point of 500 t for subsistence catch in 1950, and linearly interpolate to 0 t of true subsistence catch by 1970. Gibson et al. (2014) then apply the same proportions of taxa present in the estimated recreational catches to the subsistence catch for each year.

United Kingdom

Landings data (Reported catch)

According to Gibson et al. (2015) the Marine Management Organisation (MMO) publishes detailed annual landings data for the UK. As the UK is part of the EU "Common Pond" this data does not take into account the borders of the UK EEZ. Landings data from within the UK EEZ only for the time period 2000-2011 was obtained from the MMO through a freedom of information (FOI) request. The data from the FOI request do not provide organization by ICES management area or country fishing, which can be found in the ICES publically available database.

Gibson et al. (2015) choose to use the data provided by MMO along with estimates of earlier catch to determine the proportion of the catch which is caught within the UK's Exclusive Economic Zone (EEZ) waters. Yearly totals of the MMO data and ICES data are added together and a proportion of each is taken. These proportions represent all catch from inside the EEZ (MMO) and outside the EEZ (the difference). These proportions are applied to all ICES catch by ICES management area and taxonomic group for Scotland, England, Wales, Northern Ireland and Isle of Man. All catch from Jersey and Guernsey islands are considered within the EEZ and these proportions are not applied.

Illegal, Unreported and Unregulated catches (Unreported catch)

Unreported catch

Estimates of unreported catch comes from a report on Welsh fisheries, which estimated 10% of the total catch of vessels over 10 m being unrecorded and 50% for vessels under 10 m (NC 2000; Gibson et al., 2015).

Discards

Estimates of discards within the UK are made by targeting some of the largest fisheries. Discard to landings ratios are determined for multiple years in most cases. In order to estimate an entire time series, years with a missing ratio are interpolated or extrapolated (forward or backward). The discard to landing ratios are applied to the reported landings of target species of the fishery for total discards over the time series.

Marine Science Scotland (formerly The Marine Laboratory) in Aberdeen has been sampling and recording fish discards from the Scottish fleet since 1975 (Jermyn and Robb 1981). In order to determine a complete time series of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) discard to landing ratios, we use an average of discard to landing ratios for haddock and cod from seine and trawl fisheries from 1975-1980. An average discards to landings ratio from 1975-1980 is assigned for years 1950-2010. Additional discard to landing ratios for cod and haddock are determined using values from 2009 estimates from the Scottish demersal fleet (Fernandes *et al.* 2011). This ratio is carried forward to 2010 and all ratios between 1980 and 2009 are interpolated. The complete time series of discard to landing ratios are applied to all cod and haddock reported landings in all ICES management areas in the UK and its dependants.

<u>Recreational catch</u>
Gibson et al. (2015) use the recreational catch estimates from the reconstruction of Irelands' fisheries (Miller and Zeller 2013). The UK and Ireland are culturally similar and neither has reporting requirements for their recreational catch (Miller and Zeller 2013). Therefore, we consider Ireland to be a good proxy for estimating the UK's recreational catch. In Ireland, 1.76% of the population is considered a marine recreational fisher and 1.84% of the UK's population are marine recreational fishers, therefore our estimate is a conservative one (Pawson *et al.* 2007).

Once there is a complete time line of total annual recreational catch, the catch is split into 70% whitefish, 10% European flounder (*Platichthys flesus*) and 20% Atlantic mackerel (Pawson *et al.* 2007). The whitefish catch is split equally between pollock (*Pollachius virens*), Atlantic cod (*Gadus morhua*), whiting (*Merlangius merlangus*), European seabass (*Dicentrarchus labrax*) and Norway pout (*Trisopterus esmarkii*) (Pawson *et al.* 2007).

Norway

Landings data (Reported catch)
Nedreaas et al. (2015) used a general procedure in re-constructing the Norwegian catch statistics - first priority to the catch figures used by the ICES stock assessment working groups, second to the Norwegian official statistics, and third to the ICES officially statistics that exist electronically back to 1950.

<u>Large- versus small-scale fisheries</u>
According to official statistics, the Norwegian commercial fishing fleet consisted of 6,309 vessels in 2010 (Nedreaas et al., 2015). Thereof, 5,680 vessels are less than 15 m in length, 378 vessels are between 15-27 m, and 251 vessels are above 28 m. Vessels less than 15 m are less mobile and they conduct small-scale and more coastal fisheries. They have also restrictions on their area of operation due to safety regulations, and they are regulated as a group different from the larger offshore fleet in the national fisheries regulations. In the current re-construction, Nedreaas et al. (2015) have thus treated the vessels less than 15 m as the most practical proxy for the Norwegian small-scale vessel group.

Illegal, Unreported and Unregulated catches (Unreported catch)
<u>Discards</u>
According to Nedreaas et al. (2015), Norway introduced a discard ban on cod and haddock in 1987, for both economic and ethical reasons. The discard ban was gradually expanded to new species, and from 2009 an obligation to land all catches was introduced (with certain exemptions). It should be noted that the ban

applies to dead or dying fish, viable fish can be released back to the sea. The discard ban was preceded by a program of real time closures of fishing areas (RTCs) which was developed from 1984 on.

No routines have been established to estimate the amount of discards before and after the introduction of the discard ban, but some work and projects have been conducted for some species and fisheries to estimate the most likely amount (Nedreaas et al., 2015).

Valdemarsen and Nakken (2003) report 1-10% discards in different fisheries, usually in the 1-5% range, dependent on gear, quota, year-class strength and market. For the catch reconstruction, Nedreaas et al. (2015) have added 2% annually to the official statistics for the commercial demersal species as a minimum estimate of discards. If other sources of information existed, Nedreaas et al. (2015) increased the discard rate only if they had reason to believe that these discards were not included in the abovementioned 2% rate.

<u>Recreational and Subsistence fisheries</u>
The recreational catches presented by Norway in Nedreaas et al. (2015) represent the catches taken by foreign tourists and native Norwegians renting rooms and boats at registered tourist fishing companies. Catches taken by native Norwegians fishing for their households are included in the subsistence catches (Nedreaas et al., 2015).

The Norwegian re-construction of recreational catches by Nedreaas et al. (2015) uses the estimates by Vølstad *et al.* (2011) as an anchor point for 2009, multiplies it by a factor of 5 for ICES Subareas III and IV, to account for the other tourist fishing segments, and finally uses the time profile suggested by Hallenstvedt and Wulff (2001) to account for the development of tourist fishing in Norway.

According to Nedreaas et al. (2015) the only survey of marine household fishing by Norwegian households (i.e., subsistence) was conducted in 2003 by Hallenstvedt and Wulff (2004). A representative sample of the Norwegian population over 15 years of age were interviewed and asked to give catch per trip and total annual catch by species. In this survey, 43 percent reported that they had fished in the sea last year, or about 1.5 million people nation-wide.
Data from Hallenstvedt and Wulff (2004) show that the Norwegian population caught approximately 48,000 tonnes in 2003 for personal-, family- and household-consumption. The eastern, western and central Norway regions each caught approximately 10,000 tonnes, summing to 30,000 tonnes in total, while in northern Norway the catch was estimated at 18,000 tonnes. The catch re-construction back to 1950 has used the results from this study in 2003 as an anchor point, and extrapolated backwards and forward in time taking into account the growth of the Norwegian population and assumptions about the percentage of the population fishing in the sea (Nedreaas et al., 2015).

ICES WGNSSK report

Extracts from the WGNSSK 2016 report (ICES, 2017):

1.3 General uncertainty considerations
Data or inputs used in this report are based on sampling or on census. Typical census data are landings data from saleslips representing total landing, while sampled data are random samples (design based) used to produce estimates of total, relative indices or to characterize composition (like catch at age). All sources of input may introduce

error in estimates/calculations and is a limiting factor in the amount of information and/or interpretation of model results. The scientist at this working group are only responsible for a modest fraction of the input data used and are relying heavily on assumptions regarding their validity and quality. The information based on sampling will contain sampling errors (random errors due to the stochastic nature of such sampling) and estimates of sampling error are generally not used by this working group.

Such errors will show up in residuals (residual plots are an important diagnostic in the report), but other sources of error will also show up in the same residuals and are not easily separated from random errors. Non random errors are either bias or model errors. Systematic bias over time is a particular concern and an example of such can be underreporting of catches which will compromise the validity of the model results as basis for advice. Model errors may represent the use of the "wrong" equations to describe relations, but will in this report typically be linked to assumptions regarding natural mortality, the relationship between survey indices and stock size (catchability) and exploitation pattern. Some assumptions are needed since the Baranov and catch equations does not have unique solutions (too many parameters to estimate). Assessment working groups are in many ways end users of data and it would be preferable to have such information presented as point estimates together with estimates of uncertainty or confidence bands and with a description of potential sources of bias and qualitative remarks related to specific observations. Intercatch is still not fully operational in this respect.

The working group appreciates the effort made by so many supporting hands involved in creating all information needed in fish stock assessment and is dependent on the quality of information being upheld over time. An assessment working group is where information from the commercial fishery is handled together with fishery independent information to create estimates of stock status and the impact of fishing.

Demersal trawl surveys are the most used source of fishery independent information in this working group (WGNSSK). A demersal trawl survey uses a standardized procedure of trawling to create samples from a fish population. The "population" in statistical terms is the population of possible trawl stations with trawl station being the primary sampling unit. The estimates of uncertainty from a demersal trawl survey is very much dependent on the number of samples (trawl stations) and it seems that demersal trawl surveys on gadoid produces very similar estimates of uncertainty given the same number of trawl stations (ICES 1992) regardless of the size of the area. The relationship between sample size and precision can be illustrated using the following example: If a survey of 400 trawl stations produces an estimate (for a parameter of interest) with a corresponding relative standard error of 0.1 a reduction in survey effort to 100 trawl stations is likely to produce estimates with a relative standard error of 0.2 (divide the number of stations by 4 and the relative standard error is doubled). This is also likely to hold (at least as a rule of thumb) if one looks at results from a subarea of the original (400 station) area. When estimates of relative standard error approaches 0.3, trends over time will be very difficult to detect, and with relative standard errors above 0.3, the estimator can only be used to detect sudden events. WGNSSK recommends that along with survey index point estimates, DATRAS should also provide the uncertainty around these estimates as standard output.

14.2 Data available

14.2.1 Catch

Landings data from human consumption fisheries for recent years as officially reported to ICES together with those estimated by the WG are given for each area separately and combined in Table 14.1.

The landings estimate for 2015 is 37.2 thousand tonnes, split as follows for the separate areas (thousand tonnes):

	TAC	Landings	Discards
3.a-Skagerrak	4.2	4.6	2.9
4	29.2	31.2	9.7
7.d	1.7	1.4	0.02
Total	35.1	37.2	12.6

WG estimates of discards are also shown in the above table.
Prior to the use of Intercatch for discard estimation, discard numbers-at-age were estimated for areas 4 and 7.d by applying the Scottish discard ogives to the international landings-at-age, and were based on observer sampling estimates for area 3.a-Skagerrak. Discard raising for 2002–2015 was performed in Intercatch, with the different nations providing information by area, quarter and métier. Prior to the reform of the EU's data collection framework in 2008 (see http://datacollection.jrc.ec.europa.eu/), sampling for discards and age compositions was poor in area 7.d, and this necessitated combining areas 4 and 7.d for 2002–2008 in order to facilitate computations in Intercatch. The provision of discard information has vastly improved since 2009 and covered 70% of the landings by weight in 2015, with all nations (apart from Norway) now providing discard information. Figure 14.1a plots reported landings and estimated discards used in the assessment. Discard ratio sampling coverage by area and season for 2015 is provided in Table 14.2e, along with the contributions to total landings and discards from each area prior to raising.

Norwegian discarding is illegal, so although this nation has accounted for 7–14% of cod landings over the period 2002–2015 (Intercatch data), it does not provide discard estimates. Nevertheless, the agreed procedure applied in Intercatch is that discards raising should include Norway (i.e. Norway will be allocated discards associated with landings in reported métiers). Furthermore, tagging and genetic studies have indicated that Norwegian coastal cod are different to North Sea cod and do not generally move into areas occupied by North Sea cod. Therefore, Norwegian coastal cod data have been removed from North Sea cod data by uploading only North Sea cod data into Intercatch for 2002 onwards, and by adjusting catches prior to 2002 to reflect the removal of Norwegian coastal cod data (an annual multiplicative adjustment of no more than 2.5% was made using Norwegian coastal cod data – see ICES-WKNSEA 2015 for more details).

For cod in 4, 3.a-Skagerrak and 7.d, ICES first raised concerns about the mis-reporting and non-reporting of landings in the early 1990s, particularly when TACs became intentionally restrictive for management purposes. Some WG members have since provided estimates of under-reporting of landings to the WG, but by their very nature these are difficult to quantify. In terms of events since the mid-1990s, the WG believes that under-reporting of landings may have been significant in 1998 because of the abundance in the population of the relatively strong 1996 year-class as 2-year-olds. The landed weight and input numbers at age data for 1998 were adjusted to include an estimated 3 000t of under-reported catch. The 1998 catch estimates remain unchanged in the present assessment (apart from the adjustment for Norwegian coastal cod).

For 1999 and 2000, the WG has no *a priori* reason to believe that there was significant under-reporting of landings. However, the substantial reduction in fishing effort implied by the 2001, 2002 and 2003 TACs is likely to have resulted in an increase in unreported catch in those years. Anecdotal information from the fisheries in some countries indicated that this may indeed have been the case, but the extent of the alleged underreporting of catch varies considerably.

Marine Scotland-Compliance, a department in the Scottish government responsible for monitoring the Scottish fishing industry, operated a system intended to detect unreported or otherwise illegal fish landings (known as "blackfish"). Records show that blackfish landings have declined significantly since 2003, and is likely to be extremely low since 2006 (ICES-WKCOD, 2011). While the UK Registration of Buyers and Sellers regulation, introduced towards the end of 2005, may have had an important impact on the declining levels of blackfish landings, it is unlikely to be solely responsible, with other factors including large-scale decommissioning, and the development of targeting and monitoring systems that has substantially increased the pressure on the fleet.
The Danish Fisheries Directorate expressed the view that there is no indication of a lack of reporting of cod of any significance for vessels of ten meters and more. This view is based both on the analysis of six indicators of missing reports of landed cod, and a calculation of the difference between the total quantity of cod registered in logbooks and cod registered in sales receipts for Danish vessels over ten meters per quarter over the period 2008–2010, which has been shown to vary between approx. 0.5% and 2.5% (ICES-WKCOD, 2011).

Since the WG has no basis to judge the overall extent of under-reported catch over time, it has no alternative but to use its best estimates of landings, which in general are in line with the officially reported landings. An attempt is made to incorporate a catch multiplier to the sum of reported landings and discards data in the assessment of this stock for the period 1993–2005, but the figures shown in Table 14.2c and Figure 14.1a nevertheless comprise the input values to the assessment.

Cod NEArctic

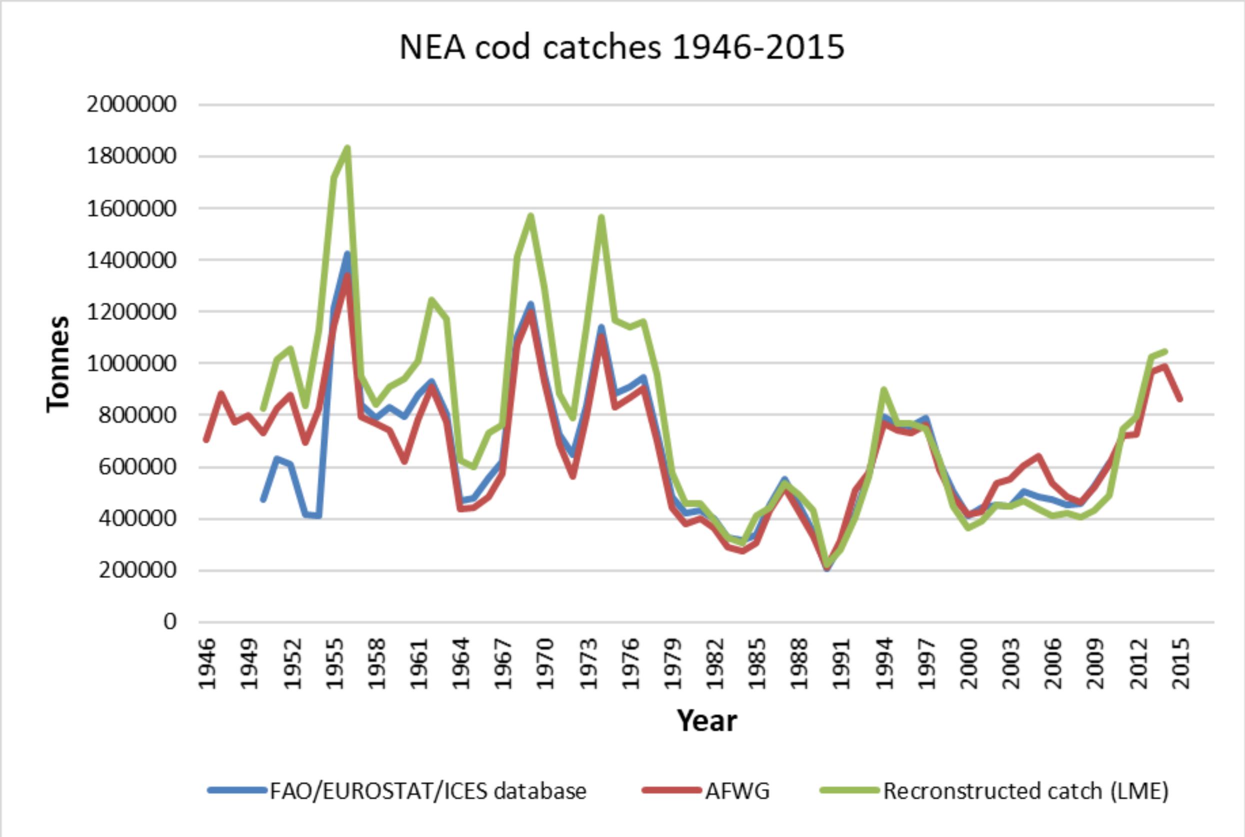


Figure 4. NEA cod catches 1946-2015. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), Reconstructed catch data from the Sea Around Us reconstruction project (green line), and the catch data used by the ICES assessment group (red line). Data in Annex 1.

Reconstructed catch data from the Sea Around Us project

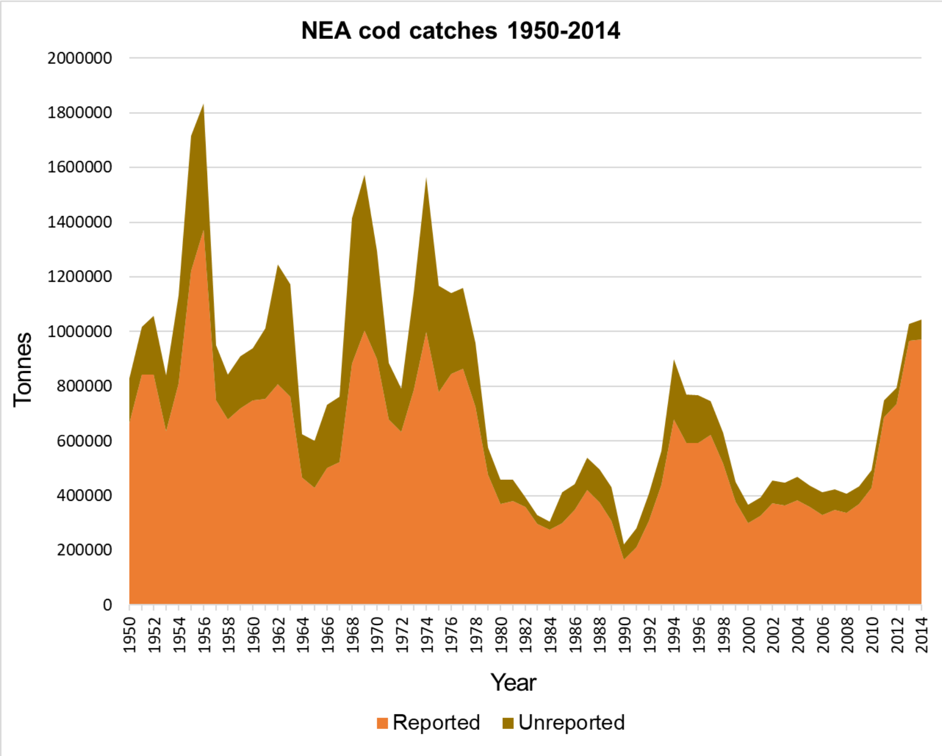


Figure 5. NEA cod reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

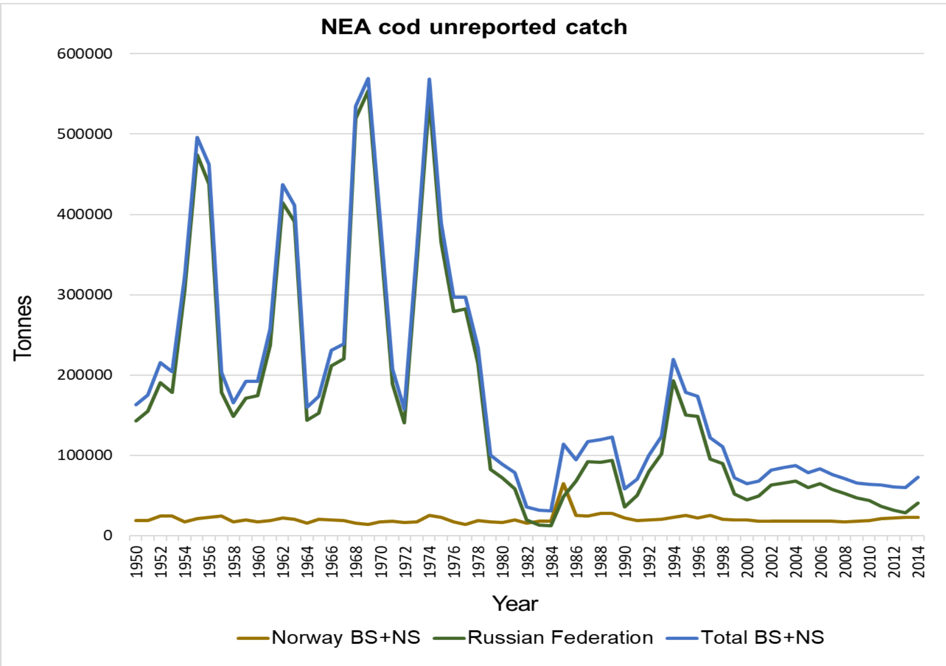


Figure 6. NEA cod unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project

Russian Federation

Landings data (Reported catch)

Jovanovic et al. (2015) estimate the total Russian fisheries catches in the Barents Sea region (ICES subarea I) between 1950 and 2010. The ICES baseline landings' database does not contain data on discards and other unreported catch. Additionally, a portion of the Russian catch from the Barents Sea has not been reported to ICES for certain years. Jovanovic et al. (2015) estimated and added five different components to the ICES baseline landings: unreported legal landings, unreported landings (mainly the result of organized crime and/or poaching), discards, subsistence catch, and recreational catch.

Illegal, Unreported and Unregulated catches (Unreported catch)

Unreported legal landings

All landings that were obtained by legal fishing methods and within the allowed annual quota for the species, but have not been reported to ICES were considered as unreported legal landings (Jovanovic et al., 2015). Data on unreported legal landings predominantly came from ICES working group reports or from national sources. Unreported landings of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) were obtained from the ICES Arctic fisheries working group report (ICES 2009).

Unreported landings (mainly the result of organized crime and/or poaching)

According to Jovanovic et al. (2015) poaching in the Barents Sea exists for Atlantic cod, haddock, and Atlantic salmon and these catches go unreported. For Atlantic cod and haddock these activities operate on the scale of organized crime and include transshipping, document falsification, and intentional misreporting of the cargo.

For the purpose of the reconstruction, Jovanovic et al. (2015) assumed that poaching activities for Atlantic cod and haddock existed since the introduction of the quota system in Russia in 1975, but were not detected until 2002, as there were no targeted inspection attempts made earlier. It is reasonable to conclude that before 1975, there were no unreported landings from poaching (i.e., fishing in excess of quota), since fishing vessels could land anything they were able to catch. The ratio of unreported catch/ICES baseline landings were calculated for the Atlantic cod for the nine year period 2002-2010 (for 2009-2010 the assumption was made that the ratio of unreported catch for reported catch was the same as in 2008). These nine ratios were summed, an additional value of zero was added to maintain a more conservative approach, and divided by ten which yielded an index of 0.29 (Jovanovic et al., 2015).

Discards

Discards of Atlantic cod were estimated using the selection curve method applied for Barents Sea and Russian fishing gear by Dingsør (2001b). This level of discard was applied for the period 1950-1987. In 1987, Russia signed an agreement with Norway for a no-discard policy of Atlantic cod (Diamond and Beukers-Stewart 2009), and since then only accidental discards of 2% per year on average were registered (Spiridonov and Nikolaeva 2005b; Burnett *et al.* 2008), with the exception of 1998, which had a 12.7% discard rate.

Subsistence and recreational catch

Jovanovic et al. (2015) assumed that subsistence fishing was negligible for any other species besides Atlantic salmon after 1950, based on the estimated five tonnes of subsistence catch of Atlantic cod in 1950 (Mokievsky 2001). Jovanovic et al. (2015) set 1990 as the first year of recreational fishing, as this was the year recreational fishing opened to the public and foreign tourists. Based on all available information, recreational fishing was not commonly practiced before 1990. Considering the report of the ICES working group on recreational fishing (ICES 2010), and based on the recreational fishing of Atlantic cod by other countries in the region, we estimated that Russia's recreational catches account for 2-8% of the country's total catch. As countries with low total landings in ICES (2010) had a higher percentage of recreational fishing, and vice versa, we assumed a 2% recreational catch for Russia since 1990. For the 1950-1998 period, 0.05-0.09% was added.

Norway

Landings data (Reported catch)
Description of the methodology behind the reconstructed Norwegian catch data is given in Nedreaas et al. (2015) – same as for North Sea cod in this report.

Illegal, Unreported and Unregulated catches (Unreported catch)
Description of the methodology behind the unreported Norwegian catch data is given in Nedreaas et al. (2015) – same as for North Sea cod in this report.

ICES AFWG report

Extracts from the AFWG 2016 report (ICES, 2016):

0.5 Uncertainties in the data

0.5.1 Catch data

At recent AFWG meetings it has been recognized that there is considerable evidence of both substantial mis-/unreporting of catches and discarding throughout the Barents Sea for most groundfish stocks having taken place (ICES CM 2002/ACFM:18, ICES CM 2001/ACFM:02, ICES CM 2001/ACFM:19, Dingsør WD 13 2002 WG, Hareide and Garnes WD 14 2002 WG, Nakken WD 10 2001 WG, Nakken WD8 2000 WG, Schöne WD4 1999 WG, Sokolov, WD 9 2003 WG, Ajiad *et al*. WD18 2005 WG, WD 24 2004 WG and WD2 2008 WG, Aanes *et al*. 2011). In addition to these WDs, Dingsør (2001) esti-mated discards in the commercial trawl fishery for Northeast Arctic cod (*Gadus morhua* L.) and some effects on assessment, and Sokolov (2004) estimated cod discard in the Russian bottom trawl fishery in the Barents Sea in 1983–2002. This work should be continued, updated and presented annually to the AFWG.

Revised and updated discards estimates (1983–2015) of cod, haddock and redfish ju-veniles in the commercial shrimp fishery in the Barents Sea are presented in Figure 0.1. It is possible to present these numbers by length and age and hence include the time series in the stock assessment. Note that the use of sorting grid does not completely solve the bycatch/discards problem of the smallest fish individuals (of the same size as the shrimps), and that in order to reduce the bycatch/discard mortality further, tempo-rally closure of shrimp fishing areas may be necessary.

In recent AFWG meetings, specific concerns have been expressed about discarding of small haddock on the nursery grounds in the Russian economic zone, and discarding of cod related to big catches when the vessel hauls the next trawl before the previous catch is processed. The combination of great amounts and fishable concentrations of cod and haddock, reduced minimum legal fish size limits in the Norwegian Economic zone and in the Svalbard area (Spitsbergen archipelago), may due to large amounts of large and better paid fish and a reduced possibility for the enforcement agencies to close small-fish areas (due to more liberal legal catch sizes), lead to a greater risk for discarding.

Discarding is now and then brought up in the Norwegian management and media debate, and quantification of the problem, whether insignificant or not, should be done routinely. A pilot study of discarding in Norwegian fisheries has been initiated by the Norwegian Directorate of Fisheries and the Norwegian Institute of Marine Research. The work is concentrated on quantifying unreported bycatch in the pelagic capelin fishery in the Barents Sea, quantification of discard in the coastal fisheries with gill nets (vessel length < 15 m), and in the bottom-trawl and autoline fisheries in selected fishing areas north of 62˚N. Results from the capelin fishery and preliminary results from the coastal gillnet fishery were presented at the FDI (Fisheries Dependent Information) conference in Rome in March 2014. The results show that during 2010–2013 up to 552 tonness of cod were caught as incidental bycatch in the capelin fishery in 2012, i.e., about 0.3% of the capelin catch. Hence a quantity of 600, 350 and 500 tonnes of the Norwegian cod quota was allocated to take account of the unreported cod caught in the capelin fishery in 2013, 2014 and 2015, respectively. In the coastal gillnet fishery between 64°N-70°N, about 150 tonnes of cod were discarded in 2012, i.e. about 0.3% of the landed and reported quantity. Estimation of discards in the bottom trawl and au-toline fisheries is still in progress. The capelin catch is not considered misreported, and discarding is considered negligible.

The Joint Norwegian-Russian Fisheries Commission (JNRFC) has defined common conversion factors for converting the weight of different products of cod and haddock to live (round) weight for all nations fishing for these species in Subarea 1 and 2. These factors have hitherto been fixed throughout the year and for all sizes of cod and had-dock. In 1999, the JNFRC decided to use 1.50 as a common factor for gutted and head-less cod (main product) in all cod fisheries in subareas I and II, and this factor has been unchanged since. Recent joint field work has been made to make these factors more precise. During a joint Norwegian-Russian survey in winter 2012 conversion factors for gutted and headless cod were estimated to 1.63 and 1.66 for cod caught by gillnet (average cod length 96.3 cm) and Danish seine (average cod length 76.3 cm), respec-tively (Anon, 2013). The conversion factors increased significantly with increasing av-erage cod length in the samples. Hence with the current size range in the cod stock, the landings by at least the coastal and seasonal fisheries may be underestimated by about 10%.

Total uncertainty in assessment

In Subbey *et al.* (2012), simulations have been used to investigate how the precision in estimates of relevant stock parameters for NEA cod relates to different levels of sam-pling effort in the trawl survey. In this paper the authors employed a statistical assess-ment model to investigate how errors in tuning series and sampling errors in catch-at-age for Northeast Atlantic Cod propagate to the estimates of biological reference points used for quota setting. Given the yearly uncertainty in estimated catch-at-age, they ex-plored how the precision in the reference points for stock assessment of NEA cod change with varying sampling effort for estimating the abundance indices by age used in tuning. Because the precision in abundance indices by age depends on the number of trawl stations and the survey design, estimates were provided of relative standard error in the spawning stock biomass (SSB) for a given effective sample size for estimat-ing the tuning indices. The modelling framework for quantifying reference points and uncertainty was implemented on the Automatic Differentiation Model Builder (ADMB) platform.

The authors also evaluated the importance of estimates of abundance-indices by age as compared to estimates of catch-at-age for assessments and management advice. Even though it is generally assumed that catch-at-age is known exactly and that uncertainty in estimates of abundance is chiefly caused by errors in the survey indices, catch-at-age is estimated, and subject to sampling errors that depend on the design and sampling effort in fisheries-dependent surveys. Hence this must be taken into account when evaluating the performance of fisheries-independent surveys.

3.1.3 Unreported catches of northeast Arctic cod (Tables 3.1)

In the years 2002–2008 certain quantities of unreported catches (IUU catches) have been added to the reported landings. More details on this issue are given in Section 0.4.

There are no reliable data on level of IUU catches outside the periods 1990–1994 and 2002–2008, but it is believed that their level were not substantial to influence on historical stock assessment.
In according to reports from the Norwegian-Russian analysis group on estimation of total catches the total catches of cod since 2009 were very close to officially reported landings.

Herring North Sea

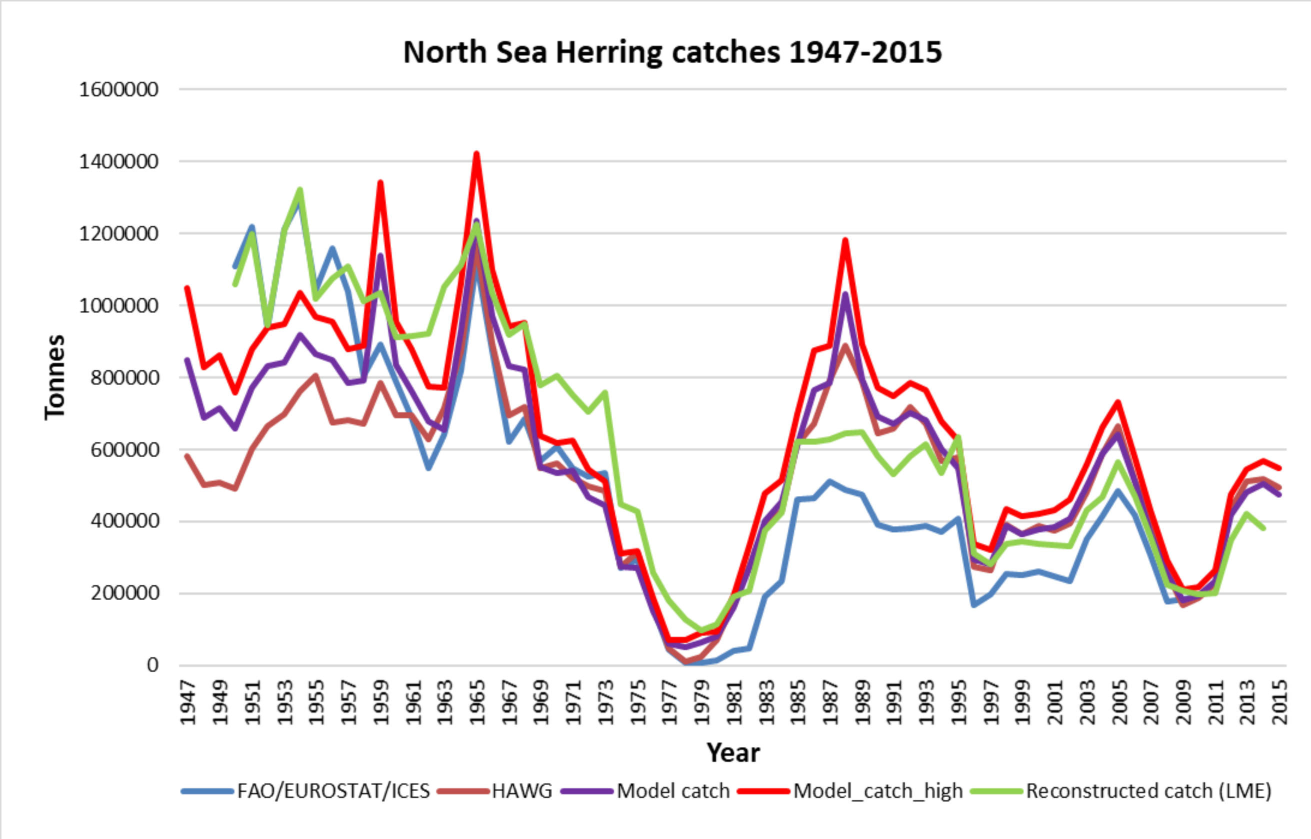


Figure 7. North Sea Herring catches 1947-2015. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), Reconstructed catch data from the Sea Around Us reconstruction project (green line), and the catch data used by the ICES assessment group (brown line). Model catch (purple line) and Model catch high (red line). Data in Annex 1.

Reconstructed catch data from the Sea Around Us project

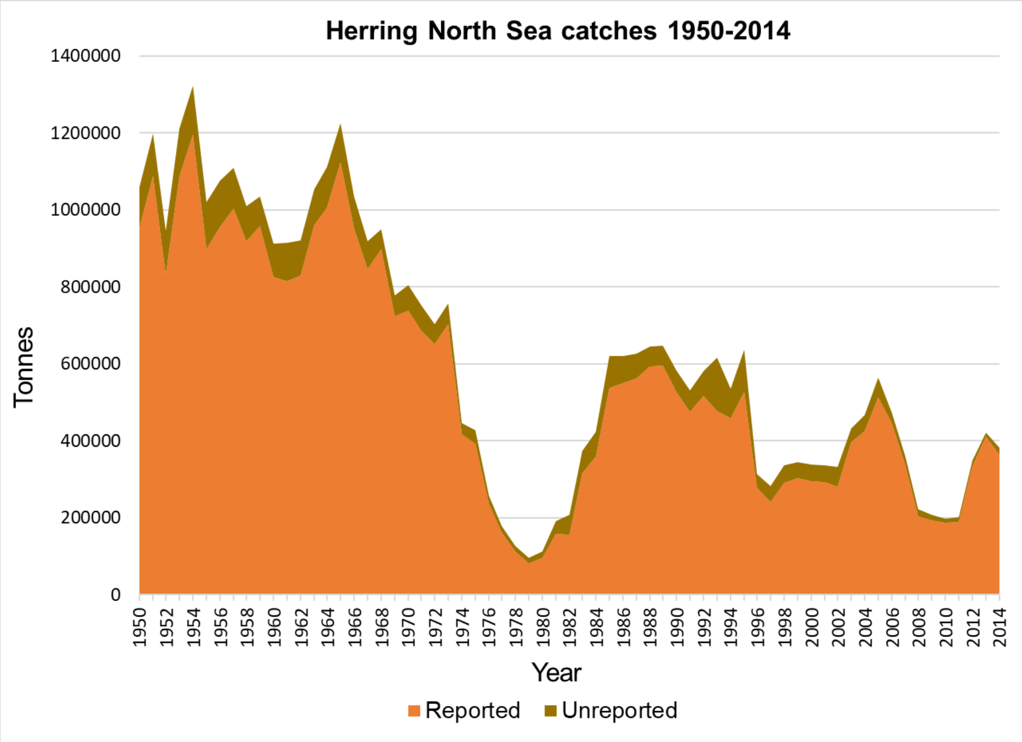


Figure 8. North Sea Herring reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

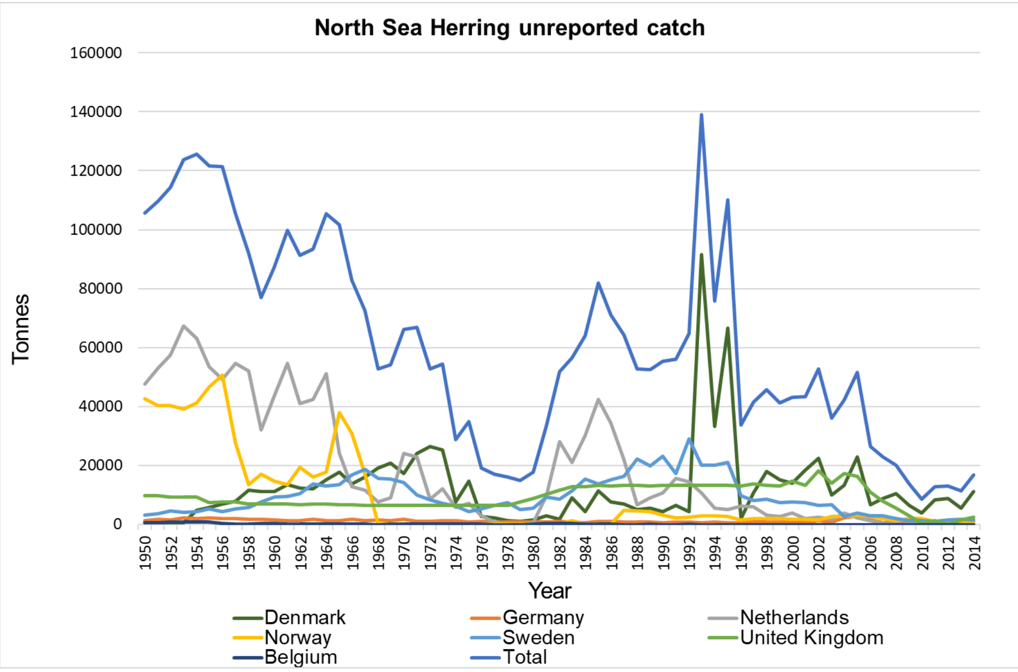


Figure 9. North Sea Herring unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project

Netherlands

Landings data (Reported catch)
Landings data are described and reconstructed by Gibson et al. (2015). Data for the Netherlands are acquired through the publically available ICES electronic landings database. The data are provided for 1950-2010 and are used as a reported baseline for this reconstruction. The Dutch EEZ equivalent waters overlap with ICES management divisions IVb and IVc. The Netherlands data are reported in various arrangements of management areas over time. From 1950-1960, all reported landings are designated area IV (not specified) or IV. Again from 1984-1987, landings are reported in area IV (not specified). For all other years, landings are reported by sub-divisions IV a, IV b and IV c.

Spatial proportions of the area IV sub-divisions (IVa, IVb and IVc) are calculated for 1958 and 1961. These proportions were applied to the total catch of area IV (unspecified) for previous years in order to better estimate catch within the EEZ equivalent waters.

For 1984-1987, spatial proportions of the area IV sub-divisions (IVa, IVb and IVc) are calculated from 1983 and 1988. The proportions are interpolated between 1983 and 1988. The interpolated proportions for 1984-1987 are applied to the IV (unspecified) total catch during this time period.

Landings data are further split into industrial (large-scale commercial) and artisanal (small-scale commercial) sectors according to gear designations in Martin (2012). For the purpose of the reconstruction Gibson et al. (2015), considered all dragged gear industrial, and as nearly all Dutch fisheries are trawls, only a few small coastal mollusc fisheries are designated as artisanal (Martin 2012).

Illegal, Unreported and Unregulated catches (Unreported catch)
Gibson et al. (2015) assume that the Netherlands share of 'unallocated' landings is proportional to their share of reported landings. Negative 'unallocated' catch is estimated due to over-reporting of catch. These values are treated as negative adjustments for the corresponding stocks and years. Gibson et al. (2015) treat positive 'unallocated' catch as unreported catch. Unreported catch is estimated by the same means as negative adjustments from 'unallocated' catch. A rate of unreported catch is calculated in relation to reported landings. The rate for the first year of unreported data is applied to all reported landings of the corresponding taxa back to 1950 for a time series of likely unreported catch. There is an exception for European plaice. The unreported rate from the second year of available data is used as a conservative assumption because it was more inline with the general trend than the first year.

<u>Discards</u>
Gibson et al. (2015) estimated a value for discards in a similar manner to the 'unallocated' catch in that there is one total discard estimate for all of Europe. Gibson et al. (2015) assume that the Netherlands proportion of total European landings is equal to its proportion of European discards for specific stocks. Discard information becomes available in the early 1990s. A discard rate based on the total estimated catch (reported landings and unreported landings) is calculated for each year with an available discard estimate. For years with missing data, the rates are interpolated and discards are then calculated. The discard rate for the first year with available data is applied to the total catch back to 1950.

<u>Discussion</u>
According to Gibson et al. (2015) unreported catch in the Dutch commercial fisheries mostly occurs as a result of the TAC quota system implemented across EU countries. Gibson et al. (2015) view positive 'unallocated' values as catch that is known to the relevant ICES working group experts, but is not assigned

to a fishing country, and are not included in the publically available database. These values are likely to be the result of some countries exceeding their TAC and not wanting to be held accountable. It is impossible for Gibson et al. (2015) to determine which countries this catch is actually coming from, so they assume that each country's 'unallocated' catch is in proportion to their reported landings share.

According to Gibson et al. (2015) it has been estimated that Dutch herring trawls discard herring at a rate of 3-6% (Kelleher 2005 supplementary material), which is nearly in line with our 3.1% (IV c) and 0.1% (IV b) for herring (1950-1993).

Norway

Landings data (Reported catch)
In the pelagic fishery for herring, mackerel, capelin, blue whiting, horse mackerel and sprat, purse seiners and pelagic trawlers catch about 89% and 10% of the total landings, respectively (Nedreaas et al., 2015). In these fisheries, Nedreaas et al. (2015) faced three main challenges when re-constructing the landings: discards of fish brought on deck, slipping of catch before it is brought on deck, and varying practices in subtracting the weight of water in the landings. The factors used to re-construct the official landing statistic are shown in Table (1) from Nedreaas et al. (2015).

Table 1. The fractions used to estimate discards, slipping and water content (in landings). Example: with a water fraction of 4% (0.04 in table), the official landing statistics have been multiplied by 1/0.96 = 1.0417.

Time period	Mackerel			**Horse mackerel**			**Herring**			**Blue whiting**	
	Discard	*Slipping*	*Water fraction*	*Discard*	*Slipping*	*Water fraction*	*Discard*	*Slipping*	*Water fraction*	*Slipping*	*Water fraction*
1950-1964	0	0	0	0	0	0	0	0.1	0	0	0
1965	0	0	0	0	0	0	0	0.1	0	0	0
1966	0	0.1	0	0	0	0	0	0.1	0	0	0
1967	0	0.1	0	0	0	0	0	0.1	0	0	0
1968	0	0.1	0	0	0	0	0	0	0	0	0
1969	0	0.1	0	0	0	0	0	0	0	0	0
1970	0	0.1	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0.1	0
1973	0	0	0	0	0	0	0	0	0	0.1	0
1974	0	0	0	0	0	0	0	0	0	0.1	0
1975	0	0	0	0	0	0	0	0	0	0.1	0
1976	0	0	0	0	0	0	0	0	0	0.1	0
1977	0	0	0	0	0	0	0.01	0.02	0	0	0
1978	0	0	0	0	0	0	0.01	0.02	0	0	0
1979	0	0	0	0	0	0	0.01	0.02	0	0	0
1980	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1981	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1982	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1983	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1984	0.01	0.02	0	0	0	0	0	0	0	0	0
1985	0.01	0.02	0	0	0	0	0	0	0	0	0
1986	0.01	0.02	0	0	0	0	0	0	0	0	0
1987	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1988	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1989	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1990	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1991	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1992	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1993	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1994	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1995	0.01	0.02	0	0	0	0	0.01	0.02	0	0	0
1996	0.01	0.02	0	0.01	0.02	0	0.01	0.02	0	0	0
1997	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0
1998	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0
1999	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0.04
2000	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0.04
2001	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0.04
2002	0.01	0.02	0.04	0.01	0.02	0.04	0.01	0.02	0.04	0	0.04
2003	0.01	0.02	0.08	0.01	0.02	0.04	0.01	0.02	0.13	0	0.04
2004	0.01	0.02	0.02	0.01	0.02	0.04	0.01	0.02	0.02	0	0.04
2005	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02
2006	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02
2007	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02
2008	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02
2009	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02
2010	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0	0.02

Illegal, Unreported and Unregulated catches (Unreported catch)

Discards

Before the introduction of individual quotas and when most of the pelagic catches were used for fishmeal (feed) and fish oil production, there were few if any incentives for discarding (Nedreaas et al., 2015). Adjustments for discards have therefore only been done once the fraction used for direct human consumption exceeded 50% (Nedreaas et al., 2015). This happened for mackerel in 1980, for herring during 1977-1983, for horse mackerel since 1996, and for blue whiting since 1999. For capelin and sprat the share for direct human consumption has been minor, and hence no estimate of discard has been added for these species. Discarding of herring and mackerel has been taken from Napier *et al.* (2002) and EU (2005), i.e., 1% for herring and mackerel in the North Sea (ICES Subarea IV) according to data from 2000-2002.

Slipping

Since there are no data of slipping of catches Nedreaas et al. (2015) have set slipping to be twice the amount of discarding, i.e., 2%. There are currently no data on the amount of slipping, but recently a PhD thesis was written about this subject at the University of Bergen (Tenningen 2014). In the mackerel and herring purse seine fisheries it happens that part of the catch is slipped if the catch is too big. Sometimes also the entire catch is slipped/discarded if the fish has poor quality, is small in size or happens to be a wrong species. In Norway, it is illegal to slip dead or dying fish, but until recently no evidence has existed on whether the fish released should be considered "dead or dying". In former years (1950-1976), slipping of mackerel was a problem when the North Sea (ICES Subarea IV) fishery was at its peak. It mainly happened when a vessel wanted to rest of the catch was slipped. During these years, the mackerel was used for fishmeal, fish oil and bait. Nedreaas et al. (2015) have no documentation of the amount slipped, but they have stipulated the slipped amount during 1950-1970 to be about 10%. Probably the same for herring, and the slipped amount has been set to 10% for the years 1950-1967. In the beginning of the blue whiting fishery (1972-1977), and before modern catch sensors were used, it happened that the nets ripped due to too excessively large catches. The blue whiting fishery has been unregulated until relatively recently, and hence had no incentives for slipping or discarding for high grading. Discard/slipping of blue whiting has hence been set to 10% during 1972-1977 (Nedreaas et al., 2015).

Water fraction

According to Nedreaas et al. (2015) subtraction of water in landed catches of pelagic fish (pumped ashore with water or landed in containers filled with water-slush) has been done in Norway since 1997. The industry claim that landing of pelagic fish contains water that they don’t want to pay for, and since 1997 the total landed weight has been reduced by an agreed factor to address this. Also before 1997, water was likely included in catch weight, and the reported landings of the actual fish species may therefore be too high since the figures include some water (but lesser and lesser the further back in history one goes due to different catch and transport procedures). The factor used since 1997 has also varied, with 2003 as a special case, before the most realistic factor has been used as a fixed factor in recent years. In our data, we have multiplied landings data with the factor used each year to get a total catch-in-container estimates (i.e., incl. water), and hence comparable with the years before 1997, and with countries not subtracting for water content. From a biological point of view, however, the most accurate estimate of the landings would, however, be to first multiply with the year specific factor used to get the total weight including water, and then to subtract the most likely amount of water (1-2%) (Nedreaas et al., 2015).

Denmark

Landings data (Reported catch)
Description of the methodology behind the reconstructed Danish catch data is given in Gibson et al. (2014) – same as for North Sea cod in this report

Denmark has a long history and tradition of industrial fishing for reduction purposes. Sandeel, sprat and Norway pout are exclusively fished for reduction purposes, and thus Gibson et al. (2014) tread their landings as 100% industrial. However, herring and cod are also caught for human consumption (fishing for juvenile herring for reduction purposes was banned). Gibson et al. (2014) split these as 50% artisanal and 50% large-scale in 1950, and 20% artisanal and 80% large-scale in 2010. Juvenile Atlantic herring was targeted for reduction purposes in the earlier decades, while mature individuals were being taken for human consumption (Byskov 2013).

Illegal, Unreported and Unregulated catches (Unreported catch)
Discards
ICES provides some estimates of discards in their stock assessment reports, and presents these estimates similar to 'unallocated' catches. For example, discards are estimated as a tonnage of herring discards as a result of targeting herring for all European countries targeting the species in a specific area. Gibson et al. (2014) assume proportionality between Denmark's portion of the total European reported catch and Denmark's portion of European discards.

The estimated unreported commercial catch totals just under 753,000 t over the time series for the taxa available. Atlantic herring comprises 62% of this value (Gibson et al., 2014).

United Kingdom

Landings data (Reported catch)
Description of the methodology behind the reconstructed UK catch data is given in Gibson et al. (2015) – same as for North Sea cod in this report

Illegal, Unreported and Unregulated catches (Unreported catch)
In 2012, in what was known as the 'Black fish scandal'[1], a number of fishermen were prosecuted for not reporting significant catches of Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) between 2002 to 2005 (170,000 t) (Gibson et al., 2015). Gibson et al. (2015) treat this, alongside extensive oral testimony from fishers, as an indicator that there was illegal fishing of herring and mackerel before this point[2]. Gibson et al. (2015) split 170,000 t between these two species over 4 years. They assume that the conviction of these fishers (alongside the parallel implementation of the Registration of Buyers and Sellers) led to a reduction in unreported pelagic landings, and by 2010, Gibson et al. (2015) reduce the illegal catch of herring and mackerel to zero. Tonnages were interpolated from 2005-2010. They also assume that the implementation of Total Allowable Catch (TAC) near the end of 1983 under the Common Fisheries Policy (CFP) increased the incentive to not report catch. They therefore carry back the unreported tonnage from 2002 to 1983 with the beginning of TACs. The unreported catch in 1978 is assumed to be 50% of the tonnage from 1983. All tonnages for years between 1978 and 1983 are interpolated. The unreported tonnage from 1978 is carried back to 1950.

[1] The Guardian http://www.theguardian.com/environment/2012/feb/24/fishing-skippers-fined-illegal-catches
[2] The Shetland Times http://www.shetlandtimes.co.uk/2012/03/02/black-fish-was-rife-in-industry-across-scotland-for-decades-says-convicted-fisherman

Belgium

Landings data (Reported catch)
Each fishery was reconstructed separately, using the baselines and other data sources (Lescrauwaet et al., 2015). An overview of the adjustments and source material is given in Table 1, see Lescrauwaet et al., (2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
<u>Herring and Sprat</u>
Having seen unprecedented catches of herring during WWII, the fishery remained important in terms of landings afterwards, particularly between 1950 and 1965 (Lescrauwaet et al., 2015). After 1965, however ≤1% of the overall fishing effort expressed as sea days (SD) is assigned to the pelagic (herring and sprat) trawl (Lescrauwaet et al., 2015).
<u>Adjustment to baseline from (Lescrauwaet et al., 2015)</u>

- Overall, the HifiDatabase positively corrected landings of herring with approximately 10 t·year^{-1} between 1950 and 1960 as under-reported compared to the ICES baseline. For sprat, differences between the two databases were only due to rounding.

- Discards: There are few historical references with regards to discards in pelagic (herring) fisheries that can be used for extrapolation in the North Sea (Garthe et al., 1996). Morizur et al. (1996) refer to the Celtic Sea (winter) herring fishery as very selective with 99.5% of the total catch by weight consisting of the target species. Discards reported by Morizur et al. (1996) amounted to 4.7% (mainly herring) by weight of the total catch. Reasons for discarding were mostly due to market requirements leading to rejection of undersized and poor quality fish. Therefore a conservative rate of 4.5% from the lower discard estimates (Table 1) was applied to both herring and sprat fisheries, with a species breakdown estimated according to Gills (1961).

- Artisanal/subsistence catches from open boats in territorial waters were carefully documented during WWII (Lescrauwaet et al., 2013 under review). Based on these records, an average of 120 t·year^{--1} of herring and 60 t·year^{--1} of sprat was added for the period 1950-1960 as a maximum for annual artisanal/subsistence catches. Lescrauwaet et al. (2015) assumed no artisanal/subsistence fishing for herring or sprat occurred after 1960, and no discards were taken into account in this artisanal/subsistence component.

Germany

Landings data (Reported catch)
According to Gibson et al. (2015) all of Germany's officially reported landings information is acquired through the ICES electronic landings database.1 Catches are reported separately from 1950-1990 by West Germany and East Germany. From 1991 to 2010, landings are reported for a re-unified Germany. From 1950-1960, all landings data are reported as ICES sub-area IV or IIIa and IV. From 1961 onwards, the data are mostly allocated to sub-divisions IVa, IVb and IVc, with the exception of a few taxonomic groups. Gibson et al. (2015) determine the proportion of area of IVb from the total area of IV, and apply this to the landings for each year in area IV from 1950-1960, i.e., they assume area proportionality of catches as a simplifying assumption. In order to create a continuous time series for 'Germany', the former Federal Republic of Germany (West Germany), former Democratic Republic of Germany (East Germany) and Germany (present Federal Republic of Germany) are combined, hence Gibson et al. (2015) treat Germany as one entity for the entire time period.

Illegal, Unreported and Unregulated catches (Unreported catch)

Gibson et al. (2015) assume proportionality between reported landings by country and 'unallocated' landings, and thus assign 'unallocated' landings to countries in proportion to their reported landings in the area. A rate of unreported catch is determined for each taxon in the first year of available unreported data in the stock assessment reports. For 1950, a rate of 5% is assumed and applied to reported landings. Rates are interpolated for each taxon between the 5% in 1950 and the first available rate from the stock assessments (Table 1 in Gibson et al., 2015). However, if the specific taxon's rate of unreported landings from the stock assessment is below 5%, that rate is carried back to 1950.

<u>High-grading</u>

Evidence for high-grading, or 'slipping' as ICES terms it (essentially a discarding of marketable catches for profit maximization), was documented for the Atlantic mackerel fishery but is likely to also occur in other fisheries.

<u>Discards</u>

Discards for the German North Sea fisheries vary greatly, based on target species and gear type. Discards are determined individually for Germany's larger fisheries. Gibson et al. (2015) used a discard rate determined for the earliest year of available data, or in some cases (if highly variable) the average of the earliest two or three years of available discard data. This rate is applied to the reported landed tonnages to determine a tonnage of discards for time periods with missing information.

Sweden

Landings data (Reported catch)

According to Persson (2014) it was not possible to extract only the Swedish west coast catches from the FAO data for area 27. Therefore International Council for the Exploration of the Sea's (ICES) catch statistics database was used (ICES 2011). All catches from the North Sea (everything except ICES areas III b-d) were considered here with unreported and discard proportions applied to all areas. ICES area IIIa contains Sweden's North Sea EEZ area.

Illegal, Unreported and Unregulated catches (Unreported catch)

Persson (2014) did not find published information on unreported commercial landings for the 1950-1990 period. Therefore, data points were created in 1950 and 1980 based on conservative assumptions: in 1950 there were no quota limitations and therefore fewer incentives to under-report catches, but also less enforcement to report catches (Anonymous source, Swedish Board of Fisheries). Therefore, a rate of 5% (of reported landings) was used as a default assumption for under-reporting of all species in 1950. During the 1970s, the quota system was introduced (Søndergaard 2007), and Persson (2014) used 1980 as a breakpoint to reflect the tendency for more unreported catches after the introduction of quotas. The anchor point for the percentage of unreported catches by species for 1980 was derived as half the rate of unreported catches per species identified for a more recent date as described below.

<u>Herring and Sprat from Persson (2014)</u>

When herring and sprat are landed on the Swedish west coast, fishers are allowed to subtract 2% of the weight of the catch as representing water (Fiskeriverket 2004). This is called the 'water adjustment factor' and was 20% in 1993 under the assumption that the fish bodies absorbed a lot of water when stored onboard. Research showed that the amount of water that the fish body actually absorbed was far from

20%. Therefore, the 'water adjustment factor' has been reduced to 13% in 2003 and to 2% in 2004 (Fiskeriverket 2004). The difference between the 'water adjustment factor' and the actual amount of water absorbed by the fish bodies has allowed for legal underreporting of catches. In a document from the Swedish Board of Fisheries on unreported catches (Fiskeriverket 2004), up to 50% of underreporting in the pelagic fisheries is acknowledged. I used 25% as an anchor point in 1993 which included the legal under-reporting (18%) due to the technical malfeasances of the 'water adjustment factor'. In 2003, the 'water adjustment factor' was decreased to 13% hence we decreased the unreported catch anchor point to 16% accordingly, in the same way the anchor point in 2004 was set to 7% when the difference in 'water adjustment factor' was taken away. Since the unreported catches are thought to have declined even further since then, 5% was applied in 2010. The earliest anchor point of 25% in 1993 was halved to 12.5% and used as an anchor point in 1980. Interpolation was done to complete the time series.

Cod, herring, and sprat are profitable species and therefore thought to have a larger fraction of unreported landings (Hultkrantz 1997). Since details for unreported catches of other taxa were not found, Persson (2014) used an assumption based fraction derived as follows. The average of the first anchor points for the profitable species (20% for cod, and 25% for herring and sprat, average = 23.3 %) was halved (i.e., 11.7%) and used as anchor point in 1990 for other species. This rate was further halved, and 5.8% was applied as 1980 and 2010 anchor points.

Discards

Due to lack of local data on discarding by Swedish fishers for many species, the discard rates from a 2004 Danish study (Anon. 2006) were used. Swedish survey data on discards were used for cod (Anon. 2007a). Herring and sprat were treated differently, as they are caught in pelagic fisheries regarded as fairly 'clean' with not much discards. Herring and sprat suffer from under-water discards (Rahikainen *et al.* 2004), which is a type of discard not considered here[3]. Therefore, herring and sprat have a discard rate of zero.

ICES HAWG report

Extracts from the HAWG 2016 report (ICES, 2016):

North Sea autumn spawning herring (her-47d3):

The North Sea herring fishery is a multinational fishery that seasonally targets herring in the North Sea and English Channel. An industrial fishery, which catches juvenile herring as a by-catch operates in the Skagerrak, Kattegat and in the central North Sea. Most fleets that execute the fishery on adult herring target other fish at other times of the year, both within and beyond the North Sea (e.g. mackerel *Scomber scombrus*, horse mackerel *Trachurus trachurus* and blue whiting *Micromestistius poutasou*). In addition, Western Baltic Spring spawners are also caught in this fishery at certain time of the year in the northern North Sea to the west of the Norwegian coast. The fishery for human consumption has mostly single-species catches, although some mixed herring and mackerel catches occur in the northern North Sea, especially in the purse-seine fishery. The by-catch of sea mammals and birds is also very low, i.e. undetectable using observer programmes. There is less information readily available to assess the impact of

[3] Note that under-water discards and ghost fishing were calculated by the author but were not utilized by *Sea Around Us* as part of their global database. Most countries' reconstructed catch data do not include estimates of under-water discards and ghost fishing, hence for the sake of consistency they were not utilized by the project.

the industrial fisheries that by-catch juvenile herring. The pelagic fisheries on herring and mackerel claim to be some of the "cleanest" fisheries in terms of by-catch, disturbance of the seabed and discarding. Pelagic fish interact with other components of the ecosystem, including demersal fish, zooplankton and other predators (sea mammals, elasmobranchs and seabirds). Thus a fishery on pelagic fish may impact on these other components via second order interactions. There is a paucity of knowledge of these interactions, and the inherent complexity in the system makes quantifying the impact of fisheries very difficult.

Another potential impact of the North Sea herring fishery is the removal of fish that could provide other "ecosystem services". The North Sea ecosystem needs a biomass of herring to graze the plankton and act as prey for other organisms. If herring biomass is very low other species, such as sandeel, may replace its role or the system may shift in a more dramatic way. Likewise large numbers of herring can have a predatory impact on species with pelagic egg and larvae stages.

The populations of herring constitute some of the highest biomass of forage fish in the North Sea and are thus an integral and important part of the ecosystem, particularly the pelagic components. The influence of the environment of herring productivity means that the biomass will always fluctuate. North Sea herring has a complex substock structure with different spawning components, producing offspring with different morphometric and physiological characteristics, different growth patterns and differing migration routes. Productivity of the spawning components varies. The three northern components show similar recruitment trends and differ from the Downs component, which appears to be influenced by different environmental drivers. Having their spawning and nursery areas near the coasts, means herring are particularly sensitive and vulnerable to anthropogenic impacts. The most serious of these is the ever increasing pressure for marine sand and gravel extraction and the development of wind farms. Climate models predict a future increase in air and water temperature and a change in wind, cloud cover and precipitation. Analysis of early life stages' habitats and trends over time suggests that the projected changes in temperature may not widely affect the potential habitats but may influence the productivity of the stock. Relatively major changes in wind patterns may affect the distribution of larvae and early stage of herring.

2.1.2 Catches in 2015

Total landings and estimated catches are given in the Table 2.1.1 for the North Sea and for each Division in tables 2.1.2 to 2.1.5. Total Working Group (WG) catches per statistical rectangle and quarter are shown in figures 2.1.1 (a-d), the total for the year in Figure 2.1.1(e). Each nation provided most of their catch data (either official landings or Working Group catch) by statistical rectangle. The catch figures in tables 2.1.1 - 2.1.5 are mostly provided by WG members and may or may not reflect national catch statistics. These figures can therefore **not** be used for legal purposes.

The total WG catch of all herring caught in the North Sea amounted to 481 611 t in 2015. Official catches by the human consumption fishery were 472 168 t, corresponding to a slight overshoot of 6% of the TAC for the human consumption fishery (445 329 t). As in previous years, the vast majority of catches are taken in the 3rd quarter in Division 4.a(W).

In the southern North Sea and the eastern Channel, the total catch sums to 41 068 t. The separate TAC for this area was 48 968 t, so 16% of the TAC remains in Division 4.c and 7.d (but due to catch regulations, 50% of the TAC could have been taken in Division 4.b). The reduced catch continues to relieve the fishing pressure on the Downs stock component, as observed since 2012.

Information on by-catches in the industrial fishery is provided by Denmark. While the Norwegian by-catches are included in the A-fleet figure for Norway, catches taken in the small-meshed fishery by Denmark account to a separate EU quota (B-fleet). Landings of herring as by-catch in the Danish small-meshed fishery in the North Sea have decreased considerably by 43% to 7 909 t in 2015 (Table 2.1.6). The by-catch ceiling for the B-Fleet was 15 744 t. Since the introduction of yearly by-catch ceilings in 1996, these ceilings have only fully been taken in 2014.

The total North Sea TAC and catch estimates for the years 2010 to 2015 are shown in the table below (adapted from Table 2.1.6).

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
TAC HC ('000 t)	164	200	405	478	470	445
"Official" landings HC ('000 t) *	166	209	414	490	490	472
Working Group catch HC ('000 t)	166	209	414	490	493	474
Excess of landings over TAC HC ('000 t)	1	9	9	12	23	28
By-catch ceiling ('000 t) **	14	17	18	14	13	16
Reported by-catches ('000 t) ***	9	9	11	8	14	8
Working Group catch North Sea ('000 t)	175	218	425	498	507	482

HC = human consumption fishery

*** Landings might be provided by WG members to HAWG before the official landings become available; they may then differ from the official catches and cannot be used for management purposes. Norwegian by-catches included in this figure.**

**** by-catch ceiling for EU industrial fleets only, Norwegian by-catches included in the HC figure.**

***** provided by Denmark only.**

Plaice North Sea

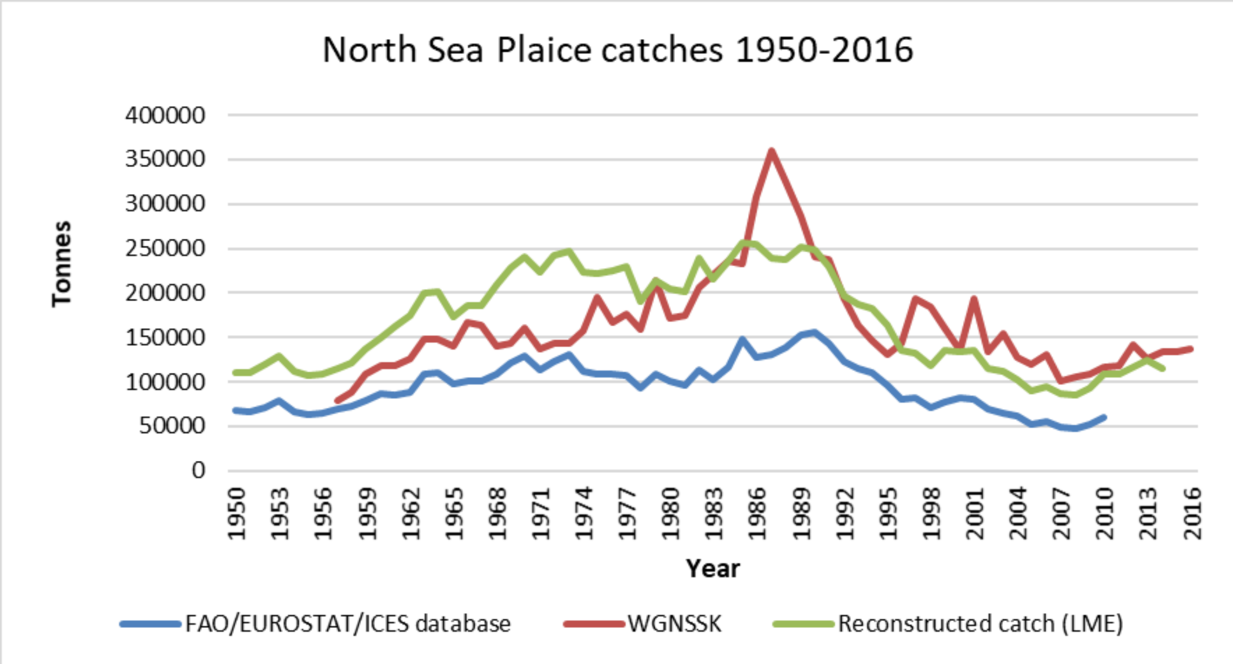


Figure 10. North Sea Plaice catches 1950-2016. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), Reconstructed catch data from the Sea Around Us reconstruction project (green line), and the catch data used by the ICES assessment group (red line). Data in Annex 1.

Reconstructed catch data from the Sea Around Us project

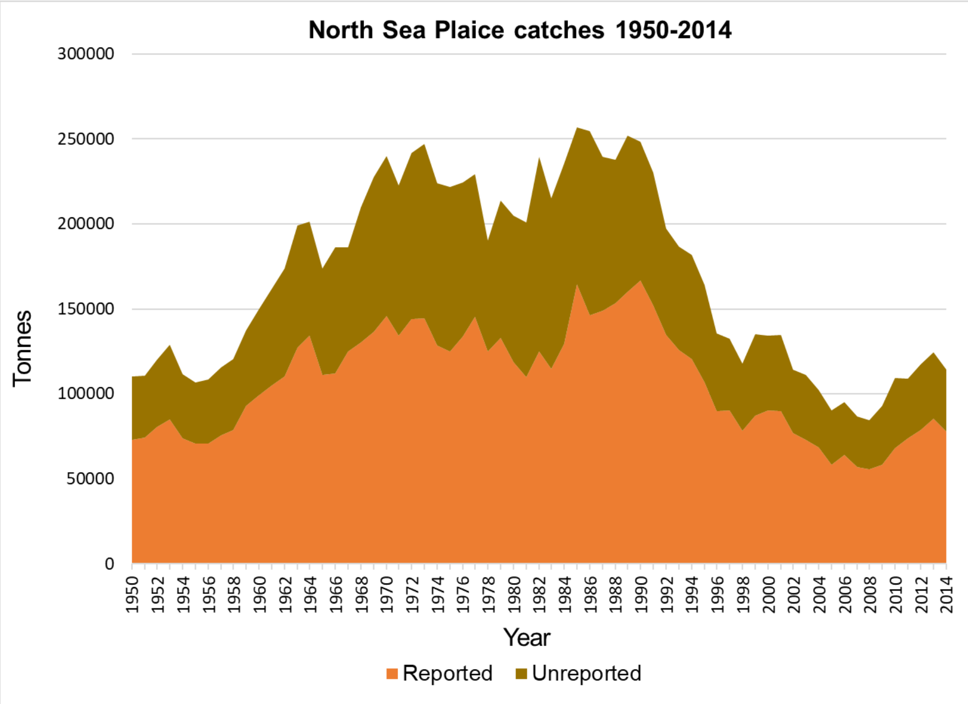


Figure 11. North Sea Plaice reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

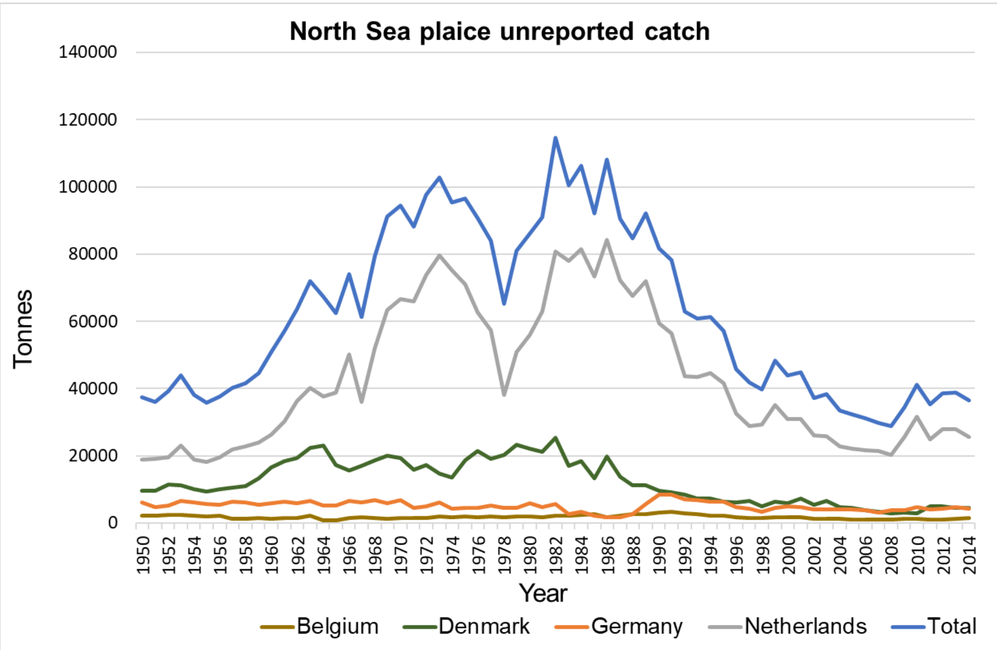


Figure 12. North Sea Plaice unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project.

Netherlands

Landings data (Reported catch)

Description of the methodology behind the reconstructed Dutch catch data is given in Gibson et al. (2015) – same as for North Sea herring in this report.

Illegal, Unreported and Unregulated catches (Unreported catch)

Gibson et al. (2015) use the rate for the first year of unreported data is applied to all reported landings of the corresponding taxa back to 1950 for a time series of likely unreported catch. There is an exception for European plaice. The unreported rate from the second year of available data is used as a conservative assumption because it was more inline with the general trend than the first year.

Discards

A value for discards is estimated in a similar manner to the 'unallocated' catch in that there is one total discard estimate for all of Europe. Gibson et al. (2015) assume that the Netherlands proportion of total European landings is equal to its proportion of European discards for specific stocks.

Further discard estimates are made for the flatfish fisheries in the Netherlands. There are no discard estimates for Dutch flatfish targeted fisheries. Flatfish landings comprise 36% of the reported landings in the Netherlands. Gibson et al. (2015) assume that flatfish discard rates in the Netherlands are similar to those from German European plaice and Common sole targeted fisheries from Ulleweit *et al.* (2010). Gibson et al. (2015) determine a total rate of discards and then divide the total proportionally amongst discarded taxa.

According to Gibson et al. (2015) Dutch discards total 7.1 million tonnes from 1950-2010. Common dab (*Limanda limanda*) and European plaice comprise 37% and 31% of discards, respectively. These discards mostly consist of juveniles from shrimp and flatfish trawl fisheries in the North Sea and Wadden Sea. Discard rates used are based on recent accounts of discarding and applied to past catches. This does not take into account that there were likely shifts in gear restrictions over this time series. However, we do not account for all fisheries in the Netherlands and we consider this to be a conservative estimate.

Discarded by-catch is one of the most important issues in European fisheries (Anon. 2008). Discarding has been a heavily overlooked problem in the Netherlands and Europe during the 20th century. It is difficult to precisely estimate discarded tonnages due to changing management decisions as well as shifts in market conditions over time (Rijnsdorp *et al.* 2006; Aarts and Poos 2009). However, having zero discards for earlier decades is not a viable solution either. There is recognition of the importance of discard data because any estimate of discards is closer to the actual catch, as reported landings are largely underestimated. The Netherlands began to collect discard data as part of an EU initiative, project 98-097, but the data were never made public as it 'upsets' many in the industry. This is a short-sighted approach, given that fish stocks are a public resource, and the use of such a public resource needs to be accounted for in a transparent manner.

Denmark

Landings data (Reported catch)

Description of the methodology behind the reconstructed Danish catch data is given in Gibson et al. (2014) – same as for North Sea cod and herring in this report.

Illegal, Unreported and Unregulated catches (Unreported catch)

Discards

Gibson et al. (2014) assume proportionality between Denmark's portion of the total European reported catch and Denmark's portion of European discards. For each taxon, an average discard rate is taken from the first three years of available data. Gibson et al. (2014) then apply the average discard rate to past catches with no available discard information. This creates discard tonnages for the entire time series 1950-2010. It is understood that changes in effort, quotas and gear restrictions over time may alter the rate of discarding. This may lead to a misreporting of Denmark's discards; however, provides the best possible estimation, since much of this information acquired by DTU is not publically available. This method of estimation is used for Atlantic herring, haddock, whiting, European plaice, Atlantic mackerel (*Scomber scombrus*) and Northern shrimp (*Pandalus borealis*). These taxa contribute approximately 22% to the total catch for Denmark. In order to estimate discards of other important taxa, we rely on data from Denmark's observer program.

European plaice represents 16% of the total discards and average 9,000 $t \cdot year^{-1}$ (Gibson et al., 2014).

Juvenile European plaice is also commonly discarded in Norway lobster and sole fisheries, as well as in shrimp fisheries (Dickey-Collas *et al.* 2007; Feekings *et al.* 2012). A combination of small mesh size, poor escapement and stress cause plaice, especially juveniles to be common in discarded by-catch. European plaice is the most important flatfish species in commercial fisheries (Madsen *et al.* 2012); however, discarding of juveniles in particular has always been a problem in Danish North Sea fisheries (Daan 1997). A 'plaice box' was established in 1989 as a protective management measure. The plaice box covers the North Sea coast of Denmark, Germany and the Netherlands (Pastoors *et al.* 2000). It also overlaps with the Danish portion of the Wadden Sea, which is completely closed for fishing except the outermost 1 nm can be trawled for shrimp (Lotze 2007). It is likely that juvenile plaice are still discarded in this fishery, however within the last 10 years, the European plaice stock in the North Sea has been increasing (ICES 2013).

Recreational catch

Flatfish species such as European plaice, European flounder (*Platichtys flesus*) and common dab (*Limanda limanda*) as well as garfish (*Belone belone*) are caught in relatively large numbers for sport purposes, but are not included in DTU Aqua surveys.

Subsistence catch

According to Gibson et al. (2014) fishing for flatfish on the western coast of Jutland occurred after World War II in small amounts (Holm 2005). From this, Gibson et al. (2014) assume that there was a small amount of subsistence fishing in the rural regions of Jutland during the early time period, and we assume that 'subsistence' *per se* ended by the 1970s. Therefore, we arbitrarily select an anchor point of 500 t for subsistence catch in 1950, and linearly interpolate to 0 t of true subsistence catch by 1970. Gibson et al. (2014) then apply the same proportions of taxa present in the estimated recreational catches to the subsistence catch for each year.

Germany

Landings data (Reported catch)
Description of the methodology behind the reconstructed German catch data is given in Gibson et al. (2015) – same as for North Sea herring in this report.

European plaice is an important fishery that contributes a significant portion of landings. There is a large decline in overall landings in the mid-1980s that likely coincides with collapsed Atlantic herring and Atlantic mackerel stocks, a strong decline in Atlantic cod, as well as a decrease in Total Allowable Catch (TAC) in the European plaice fishery (Gibson et al., 2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
In the case of the brown shrimp fishery, there is additional data available that provides more precise amounts of discards for some taxa in the earlier part of the time series. Purps and Damm (2001) provide numbers of European plaice discards from 1954-1988. The numbers of European plaice were converted to mass using the FishBase length-weight conversion function. These numbers are used in place of the estimated plaice discards in the brown shrimp fishery from Ulleweit *et al.* (2010).

Belgium

Landings data (Reported catch)
Description of the methodology behind the reconstructed Belgian catch data is given in Lescrauwaet et al. (2015) – same as for North Sea herring in this report.

Each fishery was reconstructed separately, using the baselines and other data sources. An overview of the flatfish fisheries adjustments and source material is given in Table 1 and then described in more detail below (from in Lescrauwaet et al., 2015).

Table 1: Overview of discard rates, survival rates, variables used in the calculation or as reference material for the present reconstruction, with an indication of source, by type of fisheries.

Fishery	Variable	Value	Comment	Source
Flatfish fisheries (sole and plaice)				
Flatfish beam trawl, southern North Sea	Discard rate	71-95%		Catchpole *et al.* (2005)
German flatfish and other beam trawlers, North Sea and the NE Atlantic	Discard rate	56-72%	Discards mostly composed of dab, whiting, plaice, grey gurnard and undersized brown shrimp (Ulleweit et al., 2009).	Borges *et al.* (2005) EU (2008) Ulleweit *et al.* (2009)
UK beam trawl fleet, North Sea	Discard rate	50%	Average discard rate. Discard: mainly undersized dab& plaice, species with low market value (e.g. whiting& dab)	MRAG (2007)
Beam trawls (flatfish), English Channel, Irish Sea, Celtic Sea	Discard rate	42-67%	Discard: mainly dogfish, whiting, gurnards, common cuttlefish, plaice and dab, and undersized haddock	Borges *et al.* (2005) Enever *et al.* (2007)
French benthic trawlers, Celtic Sea (1997)	Discard rate	24%	60% of discard consist of 4 bycatch species: red gurnard, horse mackerel, boar fish and grey gurnard.	Rochet et al. (2002)
Beam trawl fisheries, Belgium 2008	Discard rate	25%		Vandendriessche *et al.* (2008)
Beam trawl fisheries, North Sea	Discard survival rate	0%	Higher survival rates reported for skates (42%) and rays (55%), while sole (4%) and lemon sole (7%) discard survival rates remain below 10%.	Van Helmond and van Overzee (2008); Lindeboom and De Groot (1998)
Recreational flatfish fisheries Belgium	% of commercial catch	9%	Estimate for Based on 280 vessels*120SD*fishing days*20kg per fishing trip	This study

Illegal, Unreported and Unregulated catches (Unreported catch)

<u>Flatfish (sole and plaice) from Lescrauwaet et al. (2015)</u>

Before 1960, the Belgian fleet of steamer and motor engine powered vessels used the otter trawl as fishing gear in the 'mixed' fisheries for targeted sole and plaice. By 1965, the beam trawl had become widely introduced. In 1985, beam trawling accounted for 62% of sea days (SD) and by 2006 this segment of the fishing effort had further increased to 79% of total SD. In 2010, beam trawl represented 68% of the SD. Reported landings of plaice and sole from the commercial fleet averaged approximately 10,500 t·year^{-1} between 1950 and mid- 1980s. Between 1985 and 1995 increased annual landings of plaice raised the average to 18,200 t·year^{-1}, which then decreased to an average 11,000 t·year^{-1} for the period 1996-2010.

<u>Adjustment to baseline</u>

- Overall, HiFiData corrected the baseline with 1,000 t of unreported plaice and 1,175 t of unreported sole, mainly between 1950 and 1960

- Discards: According to Gibson et al. (2015) the current levels of discarding and discard rates in the Belgian beam trawling and found an average 25% of catch was discarded with a composition of: 2% sole, 13% plaice, 7% dab, 10% bib, 4% cod, 3% anglerfish, 13% gurnards, 7% rays, 22% sharks. Lescrauwaet et al. (2015) applied a variable discard rate from 50% at the start of the time period (the average of reported North Sea flatfish beam trawl discard rates) to 25% at the end of the time period to the reported landings. This was to account for the shift of fishing from the North Sea in the 1950s to western waters (Irish and Celtic Sea, Bristol Channel, English Channel) more recently. Lescrauwaet et al. (2015) also applied the species breakdown to the annual discard estimates.

<u>Discard survival</u>

Effects of changing or decreasing mesh size and other technological developments affecting by-catch of the gear (e.g., the short-lived introduction of the Vigneron-Dahl system, tickler chains, sumwing etc.), underwater discard mortality, and predation and infection mortality are not taken into account in the estimates. In the current exercise the precautionary approach leads to assume a survival rate at or near of zero for cod, whiting, pouting, dab, plaice and gurnards.

ICES WGNSSK report

Extracts from the WGNSSK 2016 report (ICES, 2017):

8.2.1 Landings

During the benchmark of the eastern channel (7.d) plaice stock (WKFLAT) it was decided that 50% of Q1 mature fish catches taken in the eastern channel are actually plaice from the North Sea stock migrating in and out of the area. Before 2015, 50% of the Q1 eastern channel (7.d) plaice landings were included in the assessment of the North Sea plaice stock. Since 2015, 50% of the mature fish in the landings in Q1 and of the mature fish in the discards in Q1 were added to the North Sea stock and the time series was updated, such that in previous years also 50% of the mature catches from Q1 were added. See the stock annex for plaice in division 7.d for further details.
During the benchmark on plaice (WKPLE, ICES 2015) it was decided that plaice from the Skagerrak would be added to the North Sea stock. Since, the assessment is a combined assessment with Skagerrak plaice.

Total landings (including 7.d and Skagerrak) of North Sea plaice in 2015 were estimated by the WG at 85 360t. Of these 74 963t came from the North Sea (excluding Skagerrak). This is an increase of 6% from the 2014 landings and only 58% of the 128 376t TAC for 2015. Total landings (in tonnes) are presented in Table 8.2.1 and landings in numbers at age in Table 8.2.2.

8.2.2 Discards

The discards time series used in the assessment includes Dutch, Danish, German and UK discards observations for 2000–2015, as is described in the stock annex. From Belgium, discards data have been available as well but were only used in the assessment since 2012, since it became available through InterCatch. See section 8.2.7 for more information on the use of InterCatch for raising discards rates across metiers and countries.
The Dutch discards data for 2009 and 2010 were derived from a combination of the observer programme that has been running since 2000, and a new self-sampling programme. The estimates from both programmes were combined to come up with an overall estimate of discarding by the Dutch beam trawl fleet. Since 2011, estimates were derived exclusively from the self-sampling data. There is an on-going project within IMARES to validate these estimates by examining matched (same vessel and haul) trips where both observer estimates and self-sampling estimates are derived.
To reconstruct the number of plaice discards at age before 2000, catch numbers at age data was reconstructed in 2005 based on a model-based analysis of growth, selectivity of the 80-mm beam trawl gear, and the availability of undersized plaice on the fishing grounds. Discards numbers at age are presented in Table 8.2.3. Figure 8.2.1 presents a time series of landings, catches and discards from these different sources.

8.2.3 Catch

The total catch at age as used in the assessment including all landings and all discards are presented in Table 8.2.4. These include catch of NS plaice in the 1st quarter from division 7.d and catch from the Skagerrak. Landings-at-age, discards-at-age and catchat-age plots are presented in figures 8.2.2 and 8.2.3.

Mackerel NE Atlantic

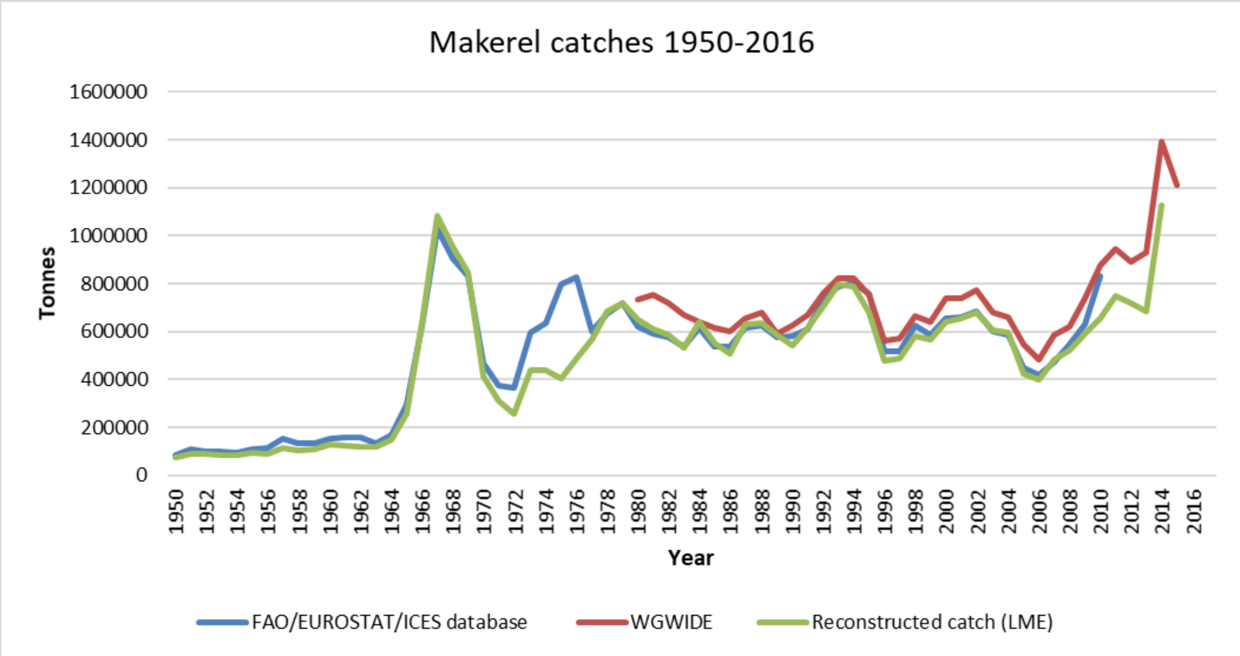


Figure 13. Mackerel catches 1950-2016. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), Reconstructed catch data from the Sea Around Us reconstruction project (green line), and the catch data used by the ICES assessment group (red line). Data in Annex 1.

Reconstructed catch data from the Sea Around Us project

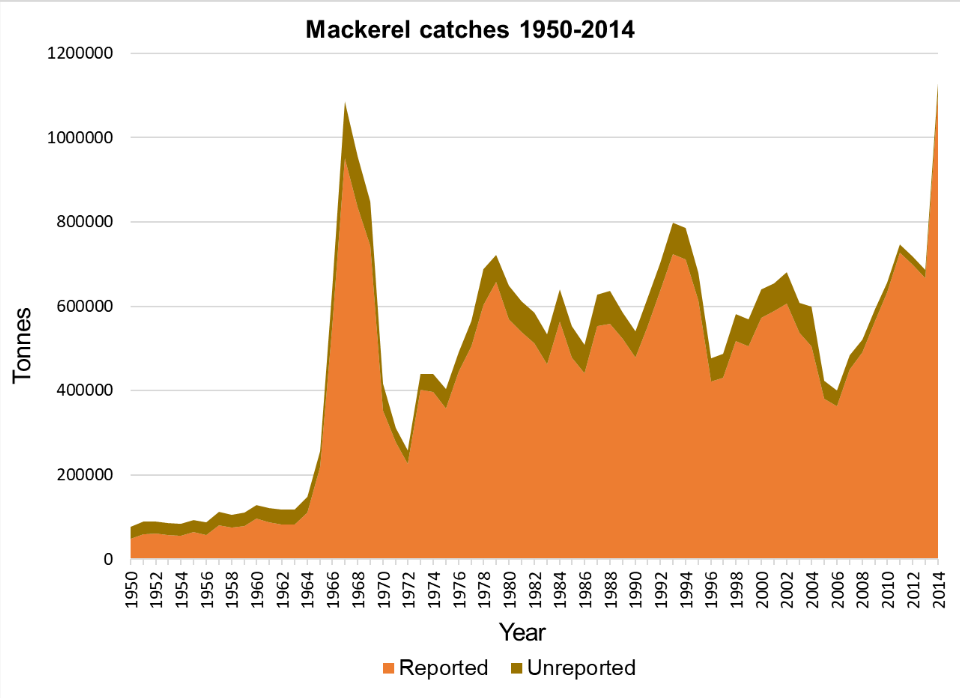


Figure 14. Mackerel reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

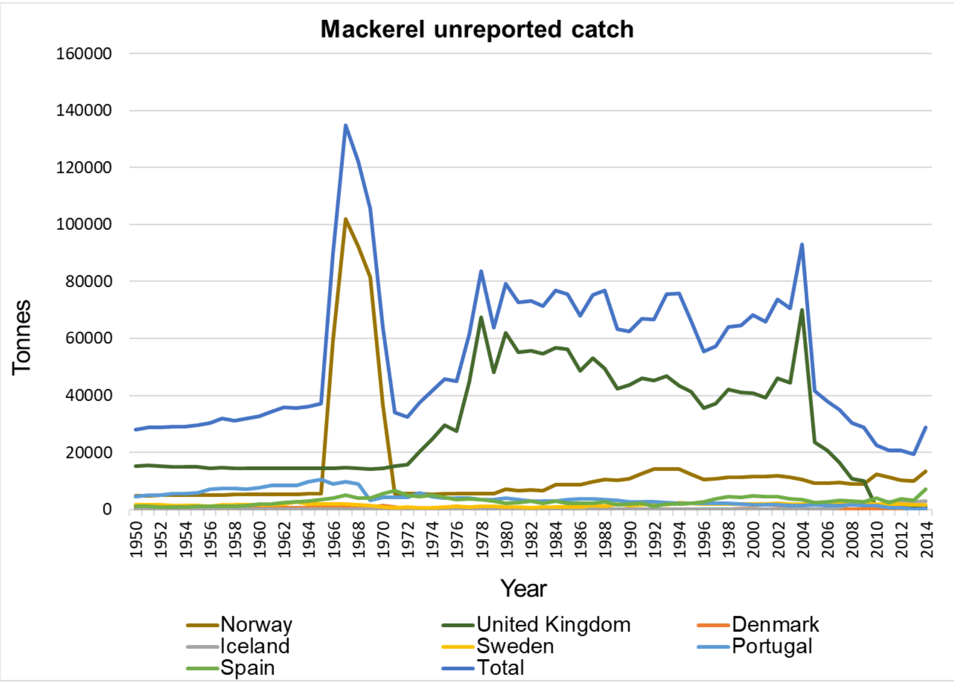


Figure 15. Mackerel unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project.

United Kingdom

Landings data (Reported catch)
Description of the methodology behind the reconstructed UK catch data is given in Gibson et al. (2015) – same as for North Sea cod and herring in this report

Illegal, Unreported and Unregulated catches (Unreported catch)
In 2012, in what was known as the 'Black fish scandal', a number of fishermen were prosecuted for not reporting significant catches of Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) between 2002 to 2005 (170,000 t). Gibson et al. (2015) treat this, alongside extensive oral testimony from fishers, as an indicator that there was illegal fishing of herring and mackerel before this point. Gibson et al. (2015) split 170,000 t between these two species over 4 years. They assume that the conviction of these fishers (alongside the parallel implementation of the Registration of Buyers and Sellers) led to a reduction in unreported pelagic landings, and by 2010, Gibson et al. (2015) reduce the illegal catch of herring and mackerel to zero. Tonnages were interpolated from 2005-2010. They also assume that the implementation of Total Allowable Catch (TAC) near the end of 1983 under the Common Fisheries Policy (CFP) increased the incentive to not report catch. They therefore carry back the unreported tonnage from 2002 to 1983 with the beginning of TACs. The unreported catch in 1978 is assumed to be 50% of the tonnage from 1983. All tonnages for years between 1978 and 1983 are interpolated. The unreported tonnage from 1978 is carried back to 1950.

Norway

Landings data (Reported catch)
Description of the methodology behind the reconstructed Norwegian catch data is given in Nedreaas et al. (2015) – same as for North Sea cod and herring in this report.

Illegal, Unreported and Unregulated catches (Unreported catch)
In the pelagic fishery for herring, mackerel, capelin, blue whiting, horse mackerel and sprat, purse seiners and pelagic trawlers catch about 89% and 10% of the total landings, respectively. In these fisheries, Nedreaas et al. (2015) faced three main challenges when re-constructing the landings: discards of fish brought on deck, slipping of catch before it is brought on deck, and varying practices in subtracting the weight of water in the landings. The factors used to re-construct the official landing statistic are shown in Table (1) - Nedreaas et al. (2015).

<u>Discards</u>
Before the introduction of individual quotas and when most of the pelagic catches were used for fishmeal (feed) and fish oil production, there were few if any incentives for discarding. Adjustments for discards have therefore only been done once the fraction used for direct human consumption exceeded 50%. This happened for mackerel in 1980, for herring during 1977-1983, for horse mackerel since 1996, and for blue whiting since 1999. Discarding of herring and mackerel has been taken from Napier *et al.* (2002) and EU (2005), i.e., 1% for herring and mackerel in the North Sea (ICES Subarea IV) according to data from 2000-2002.

<u>Slipping</u>
Since there are no data of slipping of catches Nedreaas et al. (2015) have set slipping to be twice the amount of discarding, i.e., 2%. In Norway, it is illegal to slip dead or dying fish, but until recently no evidence has existed on whether the fish released should be considered "dead or dying". In former years (1950-1976), slipping of mackerel was a problem when the North Sea (ICES Subarea IV) fishery was at its peak. It mainly

happened when a vessel wanted to add only a few more tonnes to the cargo to fill the vessel 100% before going ashore. The rest of the catch was slipped. During these years, the mackerel was used for fishmeal, fish oil and bait. Nedreaas et al. (2015) have no documentation of the amount slipped, but they have stipulated the slipped amount during 1950-1970 to be about 10%. Probably the same for herring, and the slipped amount has been set to 10% for the years 1950-1967.

Water fraction

Subtraction of water in landed catches of pelagic fish (pumped ashore with water or landed in containers filled with water-slush) has been done in Norway since 1997. The industry claim that landing of pelagic fish contains water that they don't want to pay for, and since 1997 the total landed weight has been reduced by an agreed factor to address this. Also before 1997, water was likely included in catch weight, and the reported landings of the actual fish species may therefore be too high since the figures include some water (but lesser and lesser the further back in history one goes due to different catch and transport procedures). From a biological point of view, however, the most accurate estimate of the landings would, however, be to first multiply with the year specific factor used to get the total weight including water, and then to subtract the most likely amount of water (1-2%) (Nedreaas et al., 2015).

ICES WGWIDE report

Extracts from the WGWIDE report (ICES, 2016):

1.5 Discards

From 2015 onwards a landing obligation for European Union fisheries was introduced for fisheries directed on small pelagic fish including mackerel, horse mackerel, blue whiting and herring. However, as the landing obligation is introduced stepwise by fisheries at present discarding of small pelagic species can still legally occur in other fisheries. A general discard ban is already in place for Norwegian, Faroese and Icelandic fisheries.

Historically discarding in pelagic fisheries was more sporadic than in demersal fisheries. This is because the nature of pelagic fishing is to pursue schooling fish, creating hauls with low diversity of species and sizes. Consequently, discard rates typically show extreme fluctuation (100% or zero discards). High discard rates occurred especially during ´slippage´ events, when the entire catch is released. The main reasons for ´slipping´ are daily or total quota limitations, illegal size and mixture with unmarketable by-catch. Quantifying such discards at a population level is extremely difficult as they vary considerably between years, seasons, species targeted and geographical region. Discard estimates of pelagic species from pelagic and demersal fisheries have been published by several authors. Discard percentages of pelagic species from demersal fisheries were estimated between 3% to 7% (Borges et al., 2005) of the total catch in weight, while from pelagic fisheries were estimated between 1% to 17% (Pierce et al. 2002; Hofstede and Dickey-Collas 2006, Dickey-Collas & van Helmond 2007, Ulleweit & Panten 2007, Borges et al. 2008, van Helmond et al. 2009, 2010, 2011, van Overzee et al. 2013, Ulleweit et al. 2016). Slipping estimates have been published for the Dutch freezer trawler fleet only, with values at around 10% by number (Borges et al. 2008) and around 2% in weight (van Helmond et al. 2009, 2010 and 2011) over the period 2003—2010. Nevertheless, the majority of these estimates were associated with very large variances and composition estimates of ´slippages´ are liable to strong biases and are therefore open to criticism.

Borges et al. (2008) show that for the Dutch freezer trawler fleet between 2002 and 2005, the most important commercial species discarded is mackerel, accounting for 40% of total pelagic discards. Other important discarded species are herring (18%), horse mackerel (15%) and blue whiting (8%). These discards are also the consequence of fisheries targeted at other species (e.g. mackerel in the horse mackerel and herring targeted fisheries). Boarfish was found to account for 5% of the discards. Total amount of discards by species in this fleet were estimated by van Overzee et al. (2013) for the years 2003—2012. They indicate that discards in these years for blue whiting (3.5%; range 1—16%), herring (NSSH and other stocks: 3%; range 1–7%) and horse mackerel (1.4%; range 1—5%) are low, but higher for mackerel (24.2%; range 16—37%). Dutch-owned freezer-trawlers also operate in European waters under German, UK, and French flags. Unpublished data from 2013 and 2014 show for the freezer trawler fleet of the Netherlands and Germany discard rates between < 1% to 7% for mackerel, between 0 and < 1% for horse mackerel, between < 1% and 6% for blue whiting and app. 1% for herring (all stocks).

Because of the potential importance of significant discarding levels on pelagic species assessments the Working Group again recommends that observers should be placed on board vessels in those areas in which discarding occurs, and existing observer programmes should be continued. Furthermore agreement should be made on sampling methods and raising procedures to allow comparisons and merging of dataset for assessment purposes.

1.5.1 Mackerel

The Netherlands, Spain, Germany, Ireland, Denmark, Greenland, France, England and Portugal provided discard data on mackerel to the working group. Age disaggregated data was available from Spain and Germany which indicates that the majority of the discarded catch is dominated by age 0 and 1 fish (> 85% by number). For 2015 the total mackerel discards reported were 10 431 tonnes. The working group considers this to be an underestimate (see section 8.3.1) and the discard sampling to be incomplete.

Annex 3 Special Requests

Exploring the sensitivity of the ICA assessment of NEA mackerel to misreporting in historic catches

David C.M. Miller and Claus R. Sparrevohn

WGWIDE Aug-Sep 2013

The Request

The Coastal States refer to the ICES advice on Northeast Atlantic mackerel for 2013 where it states that: "Unreported catches in the time-series cause underestimation of stock size in the analytical assessment, which is the basis of the scientific advice. The level of misreporting may have changed over time. This will remain a problem for future years, as the model cannot compensate for an unknown level of historical unreported catches." (ICES Advice 2012, Book 9, pg. 9).

Based on this

1) ICES is requested to explore and evaluate the sensitivity of the current assessment to past uncertainties in the estimates of removals.

Introduction

Anecdotal information, supported by some hard evidence, suggests that the official fish removal statistics from the mackerel fishery have in the past underestimated the actual removals. This historic misreporting is also a problem for current attempts to estimate stock size since erroneous catch statistics will result in a potentially erroneous perception of the stock. This will in turn impact on the short term forecast of the stock and thereby the advice on future fishing opportunities.

At WGWIDE 2013, it was decided to abandon the use of the ICA model for the assessment of NEA mackerel. Given this decision, there is limited value in evaluating the sensitivity of the **current** assessment to past uncertainties in the estimates of removals. The handling of catch data is specific to the particular model type being used for an assessment and it is unlikely that ICA will still be used in the assessment of the stock following the benchmark assessment in 2014. Nevertheless, it was decided that a broad analysis of the potential impacts of misreporting could be made.

Mackerel catch data

The reported catch data for NEA mackerel is considered an underestimate due to limited accounting for discarding, slippage, and illegal, unregulated, and unreported (IUU) catches (ICES 2006, Remøy et al. 2003, Simmonds et al. 2010, mackerel fishing industry representatives (WKNAMMM) *pers comm*.).

Observer coverage of the fleets fishing for mackerel has never been adequate. For most fleets there are no reliable estimates of discarding and slippage. Though discarding rates are likely to vary between fleets, estimates of discards from the Netherlands over the period 2003-2012 range from 16-37% of the landed catches. Slippage, because of mixed catches or excess catch, is a challenge to estimate regardless of the presence of observers. Highgrading, the process in which, typically the larger individuals are sorted from the catch and kept while those smaller are discarded, is equally difficult to estimate but is believed to be a problem in the mackerel fishery. Finally, black landings where a certain proportion of the fish is bypassed the official registration has also been a reality in some countries.

It is standard practice that in the process of taking the mackerel from the fishing vessel to the means of transport or the processing factory, a certain percentage of the landed weight is subtracted as water. This percentage is called the 'water content' and has prior to 2003 varied substantial between countries and years and has been as high as 10-15%. After 2003 the water content has been fixed to 2 % by a EU directive and agreement with Norway. This would lead to a relative underreporting of actually landed mackerel for the period prior to 2003 compared to present reported landings.

Simmonds et al (2010) found that to reconcile mortality estimated from the different fishery independent datasets for the period up to 2007, the landings and discards reported would have to have been between 1.7 and 3.6 times higher than the recorded catches. At the WKNAMM meeting at ICES headquarters in February 2013 (ICES 2013a), the mackerel fishing industry representatives acknowledged that the official reported catches are an underestimate of actual removals. However, they were not in a position to provide more realistic numbers as such records do not exist.

Since it is not possible to reconstruct exact values or estimates from the past, this report attempts to estimate qualitative trends in underreporting over time. This is done by dividing the NEA mackerel fishery into four temporal regimes/periods where the discrepancy between official statistics and true removals is thought to have differed. The regimes are identified from anecdotal information, and official EU and Norwegian regulations. The level of likely misreporting was primarily based on the estimated levels from Simmonds *et al.* (2010), adjusted according to the working group's opinion of the likely levels of misreporting during the four time periods, and the differences in water content percentage used over time.

1980s: Klondyking

During the 1980s there was a period known as the Klondyking period. During this period the fishery was to a large extend uncontrolled as mackerel was delivered directly from fishing vessels involved in the catch to factory vessels located offshore. Most factory vessels originated form countries within the former eastern block and this, combined with the offshore delivery, made the fishery virtually unregulated. This period ended rather abruptly around 1989, concurrent with the fall of first the Berlin wall, and then the eastern block. During this period, anecdotal evidence suggests that the unreported component of the catch was likely to have the same age structure as the reported catch. This is based upon the fact that the fishery was essentially not restricted by a maximum landings limit and the price for the mackerel in this fishery was very low at the time.

1990s: Japanese market highgrading

Subsequent to the Klondyking came a period which to a large extend was influenced by large size specific price differences. Such a size specific price difference combined with a TAC system creates a motivation for highgrading. The size specific price was a result of a demand for large mackerel (larger than 600 g) from the Japanese market. Attempts to reconstruct this price differences and use this as an index for the motivation to highgrade were made but no reliable data could be found. However, that highgrading was a problem at least up to 1999 is illustrated by a Norwegian regulation, in that year, where it was decided that only a certain (and variable) fraction of landed mackerel larger than 600 g would achieve the highest price. Such a law was designed to diminish the motivation for highgrading, and, independent of whether the regulation was effective or not, it at least implies that the problem was present prior to 1999. During this period the unreported component of the catch is likely to consist of smaller and hence younger individuals the larger, older fish.

Early 2000s: Uncontrolled IUU

In Scotland, discrepancies between official declared landings and the tonnages reported as processed by the factories were found to be large (factor of 1.6, ICES 2006). An analysis of Irish export figures estimated an overquota factor of 1.7 for the period 1988–2002 (Remøy et al. 2003), though these findings were contested (Marine Times 2003). It is unsure how the age structure of the unreported component compared to the reported catch during this period.

2006 onwards: 'Golden age' period

Since 2005 the discrepancy between official landing statistics and the true removals is believed to be relatively low compared to the earlier period described. However, Dutch discard estimates clearly show that some under reporting is still occurring. How these estimates relate to discarding rates of the rest of the fleet is uncertain.

The ICA assessment model

The ICA (Integrated Catch Analysis) assessment model consists of two main parts: a recent separable period and a VPA constructed past (Figure 1). These periods make two main assumptions when handling catch data. The VPA period assumes that catch at age estimates are exactly known. For the separable period, it is assumed that fishery selectivity at age is constant over the whole period (the last 12 years).

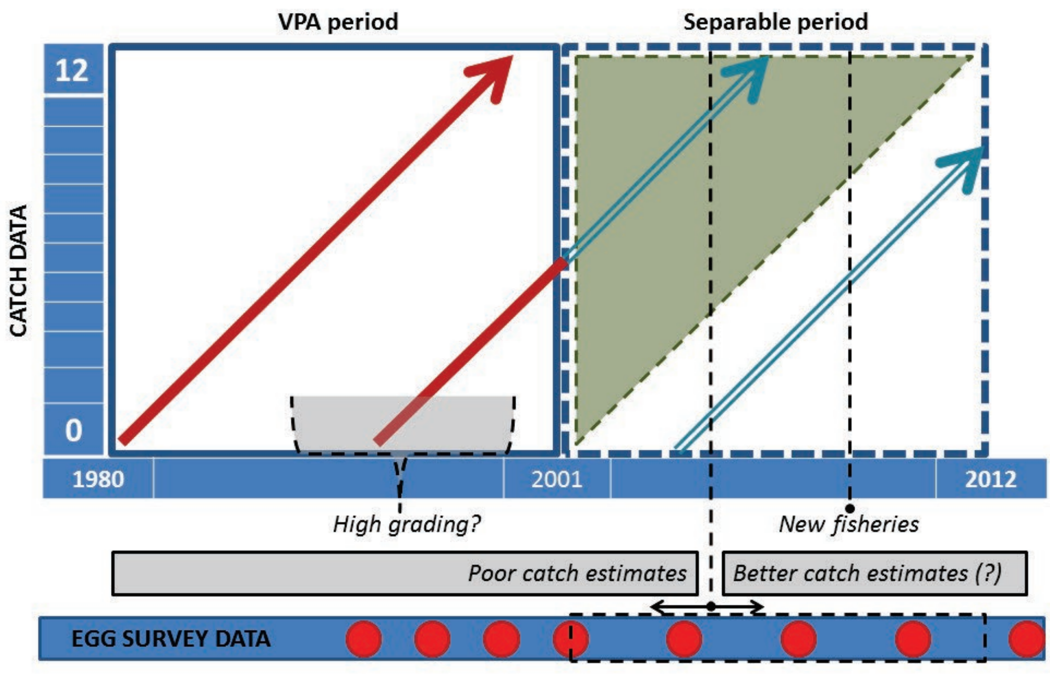


Figure 1. A schematic of the main features of the Integrated Catch at Age (ICA) model.

In Figure 1, the red arrow indicates a cohort where abundance and F estimates depend on the assumption of exact catch data, the hollow blue arrow indicate a cohort where these estimates depend on the assumption of constant selectivity, and the combination arrow indicates a cohort where these estimates depend on both assumptions. The grey shaded triangle indicates a selection of log catch residuals at age that are significantly smaller than the remaining residuals in the recent ICA fit to the data. This indicates that the selectivity pattern used in the separable period fits tighter to the cohorts that originate from the VPA period. This corresponds to a period where catch data are considered poor and there is strong potential that high grading occurred.

The assumption that catches are exactly known is one of the biggest criticisms of all VPA models, since this is very rarely considered to hold true. It is certainly not true in the case of mackerel. If the degree to which the catch at age estimates are wrong is constant over time, the trends coming out of a VPA assessment would still be acceptable. Even this assumption may not hold true in the case of mackerel. However, since the last benchmark, and the evaluation of the management plan, the consensus was that, assuming a constant proportion of unaccounted mortality, the SSB from ICA was indicative of the trend in the real SSB, and the estimated F was reliable.

The assumption of constant selectivity during the separable window is unlikely to be true for the mackerel fishery, which has changed significantly in the recent past. Over the last 12 years (the duration of the separable window), the expansion of the stock into new waters has lead to the introduction of new fishing fleets catching mackerel in new fishing areas. Most of these new fleets fish for mackerel using similar gears as the other major fleets. However, they fish at a different time of the year when the fish are more disaggregated and in areas where a higher proportion of larger mackerel are likely to occur (since larger mackerel are considered to migrate further). Catches in the northern areas (II, V, XIV) now form a greater proportion of overall catches. Additionally catch reporting is assumed to have changed within the separable window. Hence it is likely that the assumption of constant selectivity made by the ICA model is violated.

Three egg survey estimates were made during the VPA period of the model (Figure 1). Since the VPA period is incapable of producing an accurate estimate of stock size and trend with the given catch data, this has a knock-on effect into the separable period since the catchability model for the index will be influenced by how these three data points relate to the estimated stock size in the VPA period.

Methods

New catch time series (*N*=100) were generated based on the reported catch and estimates of misreporting factors. Data up to and including 2011 were used (i.e. as was done for the 2012 assessment of the mackerel stock). The ICA was then run using the same settings as described in the stock annex for each of the new catch time series. The R code used to run the analyses is included in Appendix A.

Once the four periods of misreporting had been defined, ranges of likely misreporting factors were set for each period by the working group (Table 1.) For each year in the catch time series, a misreporting factor was randomly selected from a uniform distribution between the relevant lower and upper bound.

Table 1. Estimated ranges of misreporting during the four time periods considered.

Period	Year Range	Misreporting Factor	
		Lower bound	*Upper bound*
Klondyking	1972 – 1989	1.7	3.6
Japanese market highgrading	1990 – 2000	1.7	2.5
Uncontrolled IUU	2001 – 2005	1.1	1.7
‘Golden age’	2006- 2011	1	1.1

Water content values used historically are shown in Table 2. No value was known for the period prior to 1986. Based on the assumption that the currently used 2% is an accurate estimate of the quantity of water included in catches, any percentage of water content used above this level is accounted for in the catch adjustment factor, e.g., when 10% was used between 1986 and 1999, 10-2=8% of this was likely to be mackerel, not water. Hence the catch during this period is multiplied by 1.08. These water content factors were added in addition to the misreporting factors sampled from Table 1.

Table 2. Water content values used historically for the mackerel fishery.

	1972-1985	1986-1999	2000-2003	2004 onwards
Water content %	???	10%	13%	2%
Catch adjustment factor	1	1.08	1.11	1

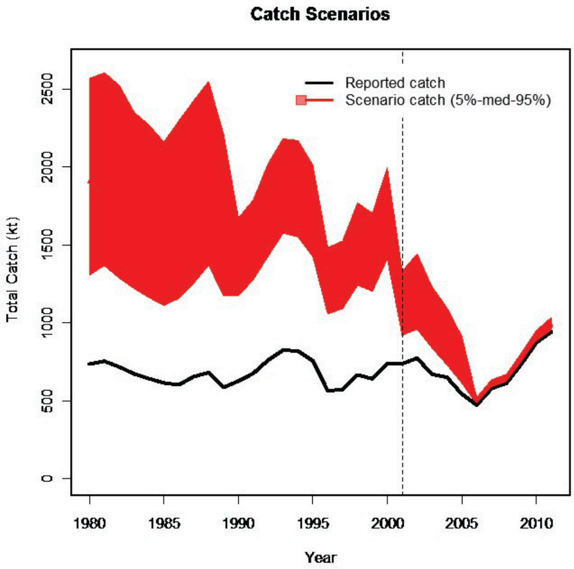
As a sensitivity test, an additional 100 time series of catch were created assuming a constant age structured bias in misreporting of catches (Table 3). These time series of estimated catch assumed the same total catch (including misreporting factors and water content corrections had been applied to the reported catch) but distributed the misreporting more over the young ages. The values in Table 3 were use to multiply up the numbers at age in the catch matrix. Following this a SOP (sum of products) correction was done to ensure that the total catch weight in each year was the same.

Table 3. Vector of possible relative misreporting by age.

Age:	**0**	**1**	**2**	**3**	**4**	**5+**
Relative contribution to misreporting	1.5	1.3	1.3	1.2	1.1	1

Results

The resultant distribution of total catch for the 100 scenarios in comparison with the reported catch is shown in Figure 2. The high estimated rates of misreporting prior to 2000 result in both quantitative and qualitative differences in catch level. The reported catch is remarkably stable over time for a pelagic species and indicates that recent removals are amongst the highest in the time series. Conversely, the estimated catch fluctuates at a higher level prior to 2000 before declining. This results in the catches in recent years being amongst the lowest in the time series. Figure 3 compares the inputted catch levels with the catch estimated by the model. These are identical during the VPA period, but differ in the separable period (last 12 years) when catch is not taken as exact and constant selectivity is assumed. In the separable period, the fishing mortality applied to the numbers at age in the ICA model produces model estimated values for catch in those years that may differ from the inputted catch data. For the last three years the model fit estimates that catches are lower than those estimated.



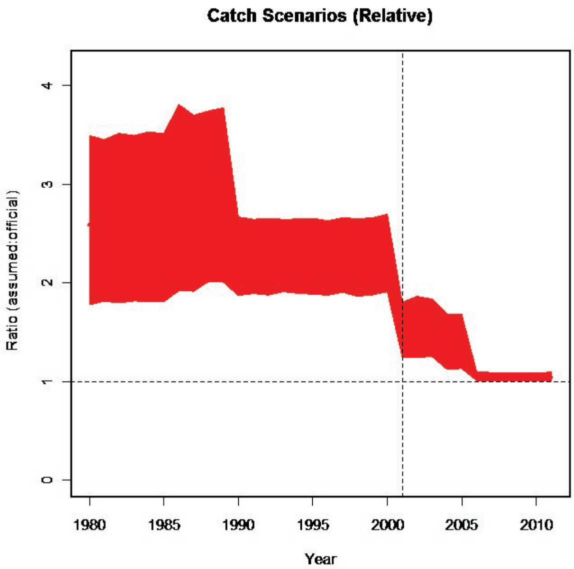


Figure 2. Reported (black) and estimated (red; 'scenario') catch (left) and the relative difference between the two (right). The shaded area represents the 5-95% range. The vertical dashed line indicates the start of the separable period in the ICA model.

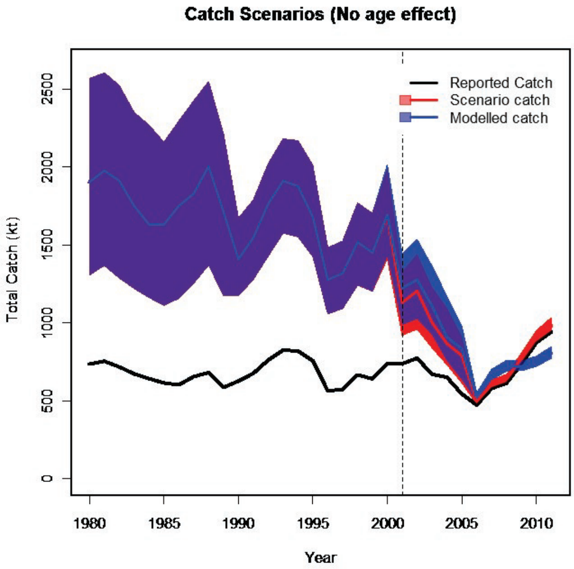
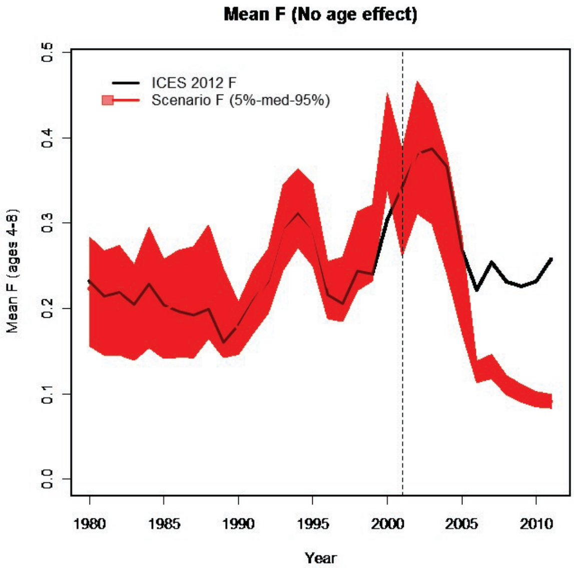
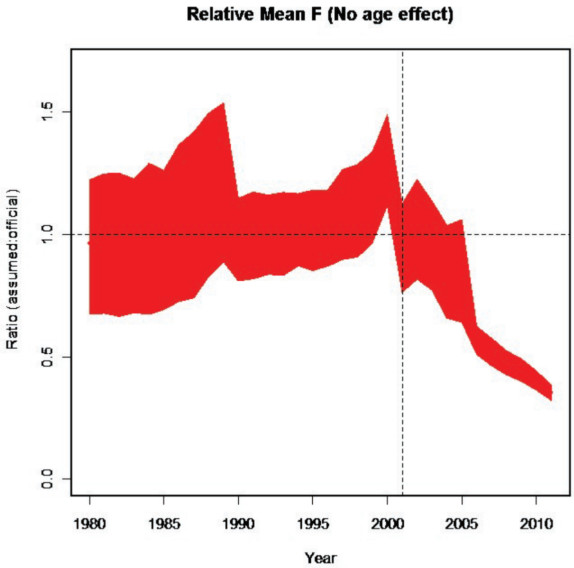
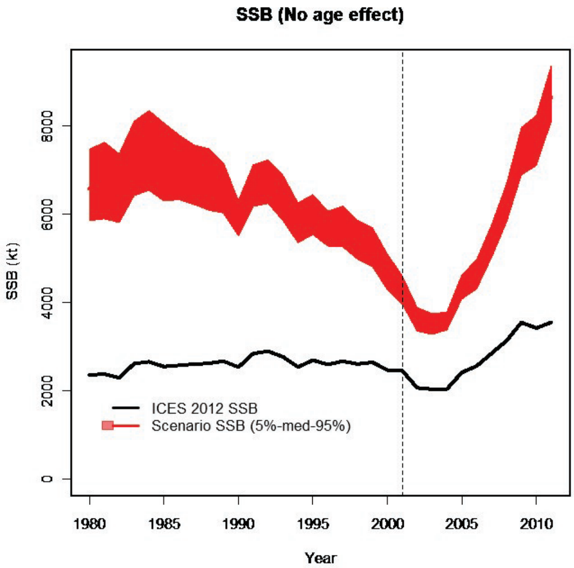


Figure 3. Reported (black), estimated (red) and model fit (blue) total catch. The shaded areas represents the 5-95% range. The vertical dashed line indicates the start of the separable period in the ICA model.

Figure 4 shows the resulting stock metrics (mean F, SSB and recruitment) from the ICA models fit to the reported and estimated catch data. Using the estimated catch time series results in similar estimates of F during the VPA period, but lower estimates of F during the separable period. The degree to which mean F is overestimated using the reported catch (relative to the estimated catch) increases in the most recent years. SSB is estimated to be significantly higher using the estimated catches. The degree to which SSB differs is highest during the Klondyking period and decreases as the level of misreporting is estimated to decrease. Conversely to the pattern in mean F, the degree to which SSB is underestimated using the reported catch (relative to the estimated catch) increases in the most recent years. Similarly to the SSB, recruitment levels are scaled up when estimates of misreporting are taken into account.


Mean F (No age effect)
ICES 2012 F
Scenario F (5%-med-95%)
Mean F (ages 4-8)
0.0
0.1
0.2
0.3
0.4
0.5
1980
1985
1990
1995
2000
2005
2010
Year


Relative Mean F (No age effect)
Ratio (assumed:official)
0.0
0.5
1.0
1.5
1980
1985
1990
1995
2000
2005
2010
Year


SSB (No age effect)
ICES 2012 SSB
Scenario SSB (5%-med-95%)
SSB (kt)
0
2000
4000
6000
8000
1980
1985
1990
1995
2000
2005
2010
Year

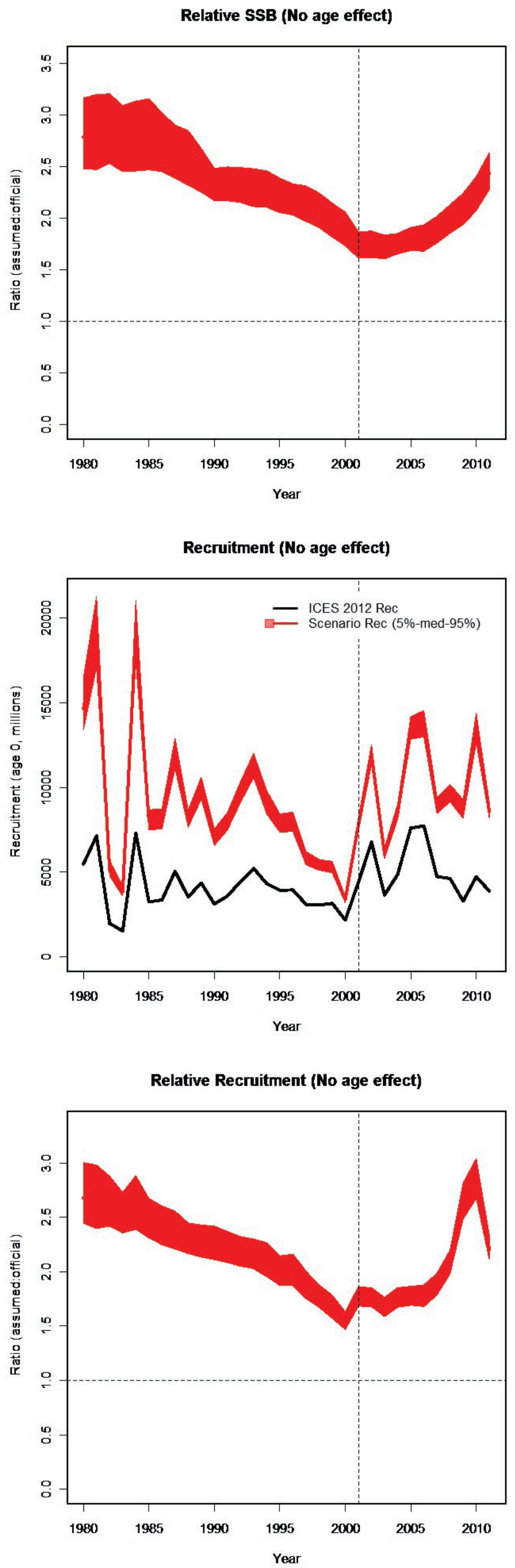


Figure 4. Comparison of absolute (left) and relative (right) outputs from ICA assessments using the reported (black) and estimated (red) catch time series: Mean fishing mortality for ages 4-8 (top), spawner stock biomass (middle) and recruitment (bottom). The shaded areas represents the 5-95% range. The vertical dashed line indicates the start of the separable period in the ICA model.

Figure 5 shows a comparison of the results with and without an age effect in misreporting. The patterns in mean F, SSB and recruitment are all very similar. Likewise for mean F and recruitment the absolute values estimated are very similar. Only for SSB is a slightl scaling difference observed, with the catch estimates including a higher degree of younger fish in the misreported component resulting in slightly lower estimates of SSB.

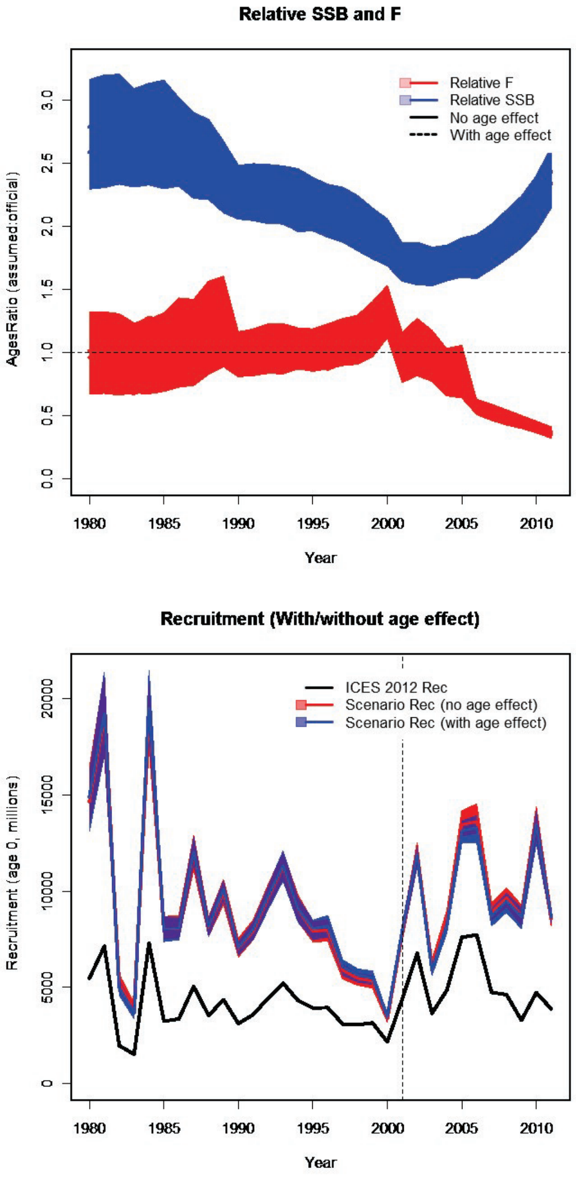


Figure 5. Comparison of assessment outputs assuming catch misreporting with or without an age effect. Left: the relative change in SSB (blue) and Mean F (red) compared to the assessment using reported catch with (dashed) and without (solid) an age effect in misreporting. Right: absolute estimates of recruitment with (blue) and without (red) an age effect in the misreporting. The shaded areas represents the 5-95% range. The vertical dashed line indicates the start of the separable period in the ICA model.

Discussion

The catch levels estimated form the misreporting scenarios show a very different pattern from the reported catch. Since all reported catch values were assumed to be underestimates, the estimated catch values are higher than reported values, becoming more similar with time. While the reported catch suggests that current levels are the highest of the time series, the estimated levels show recent years to be amongst the lowest. This is a significant qualitative difference that not surprisingly produces different patterns in the estimated levels of fishing mortality and spawner stock biomass.

Most of the scaling that occurs with the higher estimated catches is observed in the estimates of recruitment and SSB. The SSB values that result from the assessment fit to the estimated catch values are significantly higher than those from the current ICA assessment and are more in line with levels estimated from other data series (e.g. absolute SSB estimates from the egg survey (ICES 2013b) and the IESSNS swept area survey).

Mean F is similar over the period prior to 2000. However, as the level of misreporting is assumed to be more accurate the degree to which F is overestimated by the current assessment increases relative to the assessment using the estimated catch values. At previous WGWIDE meetings the conclusions of Simmonds et al. (2010) that the level of fishing mortality and trends in SSB are likely to be robust to the misreporting in catch were used as a rationale for continuing to use the ICA assessment. However, Simmonds et al. (2010) only used data up to 2007. Since then catches are assumed to be reported more accurately in the past. The results here indicate that this leads to a deviation from the assumption of accurate F estimation in recent years. Also, when the level of misreporting is assumed to vary over time, the trends in SSB are no longer accurately estimated either.

The estimated catch levels generated here are considered to be broadly representative of the true history of catch in this fishery. However, the level of quantitative accuracy for any given year is likely to be poor. Also, in the absence of good data, the current level of misreporting cannot be accurately estimated. The conclusions of this sensitivity analysis to a large degree depend on the assumption that recent catch is better estimated relative to the past. However, the last 5 years have seen conditions that would allow opportunities for highgrading: an apparently growing stock, with large incoming year classes and potential limiting TACs for the fishery. However, assuming that the levels of misreporting are correctly estimated, these results suggest that the current ICA assessment using reported catch is potentially giving misleading levels and trends of both SSB and fishing mortality.

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Haddock North Sea

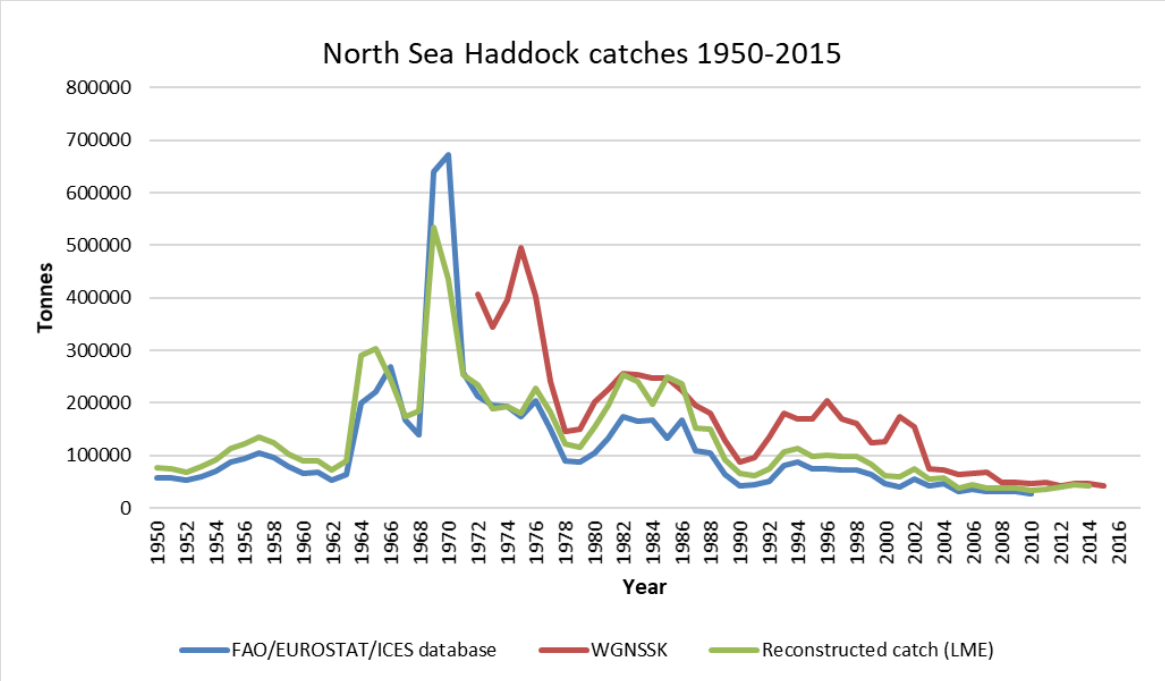

Figure 16. North Sea Haddock catches 1950-2015. Comparisons of the official catch data 1950-2010 from FAO/EUROSTAT/ICES database (blue line), Reconstructed catch data from the Sea Around Us reconstruction project (green line), and the catch data used by the ICES assessment group (red line). Data in Annex 1.

Reconstructed catch data from the Sea Around Us project

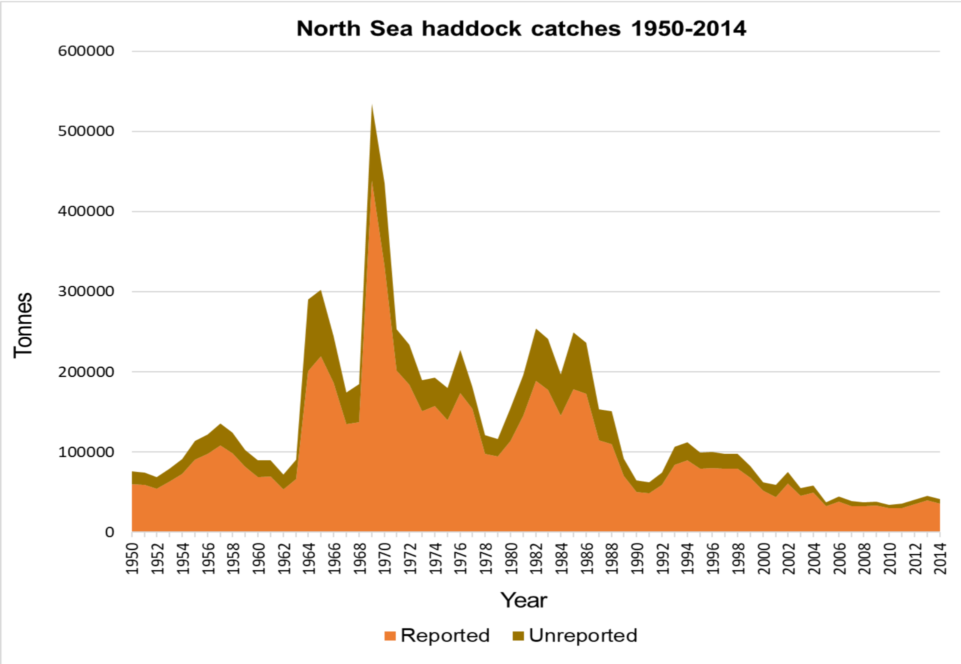

Figure 17. North Sea Haddock reported and unreported catches 1950-2014. Reconstructed catch data from the Sea Around Us reconstruction project.

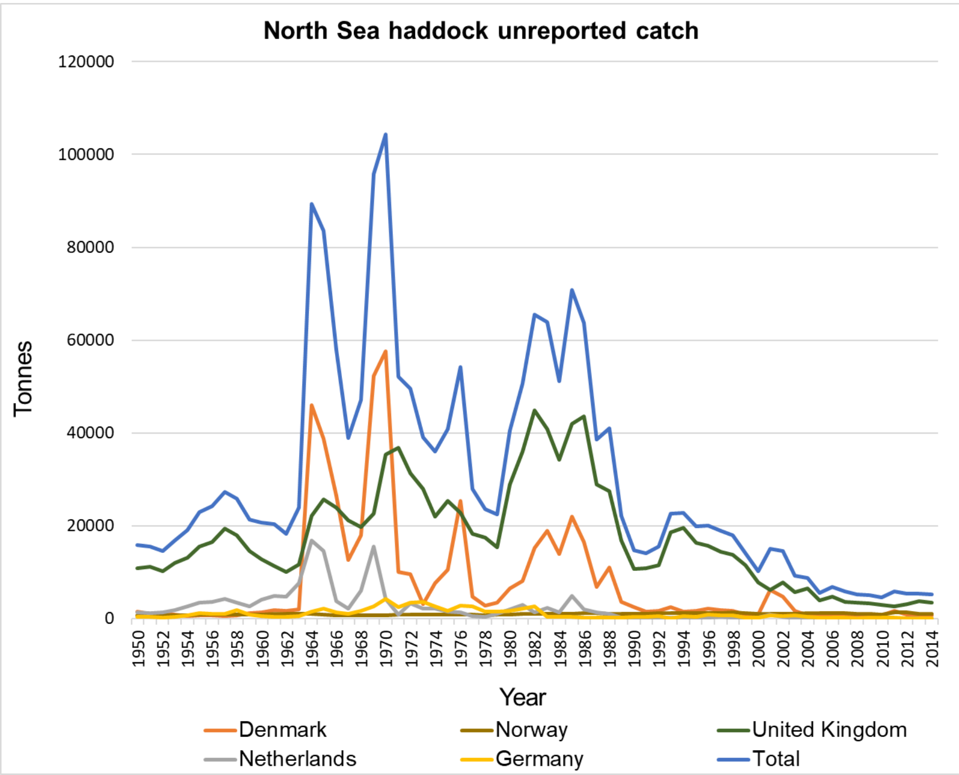

Figure 18. North Sea Haddock unreported catches 1950-2014 and dominating countries. Reconstructed catch data from the Sea Around Us reconstruction project.

United Kingdom

Landings data (Reported catch)
Description of the methodology behind the reconstructed UK catch data is given in Gibson et al. (2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
Marine Science Scotland (formerly The Marine Laboratory) in Aberdeen has been sampling and recording fish discards from the Scottish fleet since 1975. In order to determine a complete time series of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) discard to landing ratios, Gibson et al. (2015) use an average of discard to landing ratios for haddock and cod from seine and trawl fisheries from 1975-1980. An average discards to landings ratio from 1975-1980 is assigned for years 1950-2010. Additional discard to landing ratios for cod and haddock are determined using values from 2009 estimates from the Scottish demersal fleet (Fernandes *et al.* 2011). This ratio is carried forward to 2010 and all ratios between 1980 and 2009 are interpolated. The complete time series of discard to landing ratios are applied to all cod and haddock reported landings in all ICES management areas in the UK and its dependants.

Denmark

Landings data (Reported catch)
Description of the methodology behind the reconstructed Danish catch data is given in Gibson et al. (2014).

Illegal, Unreported and Unregulated catches (Unreported catch)
ICES provides some estimates of discards in their stock assessment reports, and presents these estimates similar to 'unallocated' catches. For example, discards are estimated as a tonnage of herring discards as a result of targeting herring for all European countries targeting the species in a specific area. Gibson et al. (2014) assume proportionality between Denmark's portion of the total European reported catch and Denmark's portion of European discards. For each taxon, an average discard rate is taken from the first three years of available data. Gibson et al. (2014) then apply the average discard rate to past catches with no available discard information. This creates discard tonnages for the entire time series 1950-2010. It is understood that changes in effort, quotas and gear restrictions over time may alter the rate of discarding. This may lead to a misreporting of Denmark's discards; however, provides the best possible estimation, since much of this information acquired by DTU is not publically available. This method of estimation is used for e.g. haddock (Gibson et al., 2014).

Netherlands

Landings data (Reported catch)
Description of the methodology behind the reconstructed Dutch catch data is given in Gibson et al. (2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
Discard estimates are taken from ICES stock assessments for haddock (*Melanogrammus aeglefinus*). A value for discards is estimated in a similar manner to the 'unallocated' catch in that there is one total discard estimate for all of Europe. Gibson et al. (2015) assume that the Netherlands proportion of total European landings is equal to its proportion of European discards for specific stocks. Discard information becomes available in the early 1990s. A discard rate based on the total estimated catch (reported landings and unreported landings) is calculated for each year with an available discard estimate. For years with missing data, the rates are interpolated and discards are then calculated. The discard rate for the first year with available data is applied to the total catch back to 1950.

Norway

Landings data (Reported catch)
Description of the methodology behind the reconstructed Norwegian catch data is given in Nedreaas et al. (2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
Norway introduced a discard ban on cod and haddock in 1987, for both economic and ethical reasons (Nedreaas et al., 2015). The very existence of the ban has been beneficial in changing the attitudes of fishermen attitudes and discouraging the practice of discarding.

Germany

Landings data (Reported catch)
Description of the methodology behind the reconstructed German catch data is given in Gibson et al. (2015).

Illegal, Unreported and Unregulated catches (Unreported catch)
Discard estimates are after the same method as for e.g. the Netherlands.

ICES WGNSSK report

Extracts from the WGNSSK 2016 report (ICES 2017):

13.2.1 Catch
Official landings data for each country participating in the fishery are presented in Table 13.2.1, together with the corresponding WG estimates and the agreed international quota (listed as "total allowable catch" or TAC). Since 2012, international data on landings and discards have been collated through the InterCatch system (see Section 1.2). Figure 13.2.1 and Tables 13.2.2 to 13.2.4 summarise the proportion of landings in the combined Northern Shelf area, for which samples have been provided. While there are a large number of fleets for which landings have not been sampled, the overall contribution of these fleets to total landings is small and more than 90% of landings by weight have been sampled appropriately. Age compositions for the remaining landings have therefore been determined by averaging across the available sampling (as for last year), without consideration of quarter, country or gear type. Similarly, discard observations are available for the fleets landing the vast majority of haddock (see Figure 13.2.2), so discard rates for the remaining fleets have also been inferred using simple averaging. The full time series of landings, discards and industrial by-catch (IBC) is presented in Table 13.2.5. These data are illustrated further in Figure 13.2.3. The total landed yield of the international fishery has been relatively stable since 2007. The WG estimates (Table 13.2.5) suggest that haddock discarding (as a proportion of the total catch) decreased significantly during 2013, and the discard rate for that year was the lowest in the time series at 7.2% by weight. This may have been due in part to fleet behaviour changes related to cod avoidance measures, but also to the weak year-classes since 2009 (implying that the bulk of the catch was large, mature fish that are less likely to be discarded). The discard rate increased once more to around 11% by weight in 2014 and around 15% in 2015, although the reasons for this are not known. The recent changes

in discarding are not consistent across ages (Figure 13.2.4).
Subarea 4 discard estimates are derived from data submitted by Denmark, Germany, England and Scotland. As Scotland is the principal haddock fishing nation in that area, Scottish discard practices dominate the overall estimates. DCF regulations oblige only the UK (Scotland and England) and Denmark to submit discard age-composition data for Subarea 4. Division 3.a discard estimates are derived from data submitted by Denmark. Division 6.a discard estimates are provided by UK (Scotland) and Ireland. Industrial bycatch (IBC) has declined considerably from the high levels observed until the late 1970s.

Estimated discard rates can be calculated using video data from Scottish vessels carrying cameras (as part of the FDF scheme described in Section 13.1.2). Neither fish ages nor weights can be measured directly using video, but a method has been developed in Scotland for estimating discard rates by measuring numbers and lengths of discarded fish and applying existing weight-length relationships to obtain a discarded weight, which can then be compared with the total landed weight (see Needle et al 2015). The lack of age information currently impedes the use of these estimates in the ICES assessment process, but work is underway in Scotland and elsewhere to address this.

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Data sheets

Cod North Sea

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT/ ICES database	Reconstructed catch (LME)	ICES WGNSSK Landings + discards
1950	133746	116915	
1951	61487	111123	
1952	76798	129663	
1953	81357	131264	
1954	80766	133199	
1955	83751	135298	
1956	81073	132278	
1957	95897	154272	
1958	104635	163454	
1959	109755	165730	
1960	104755	163154	
1961	108221	161840	
1962	89815	150615	
1963	106220	167337	117830
1964	114003	174965	145074
1965	171928	242887	199187
1966	209188	278403	241108
1967	241545	304310	287506
1968	276710	368393	293608
1969	194491	267904	226840
1970	218370	265890	252458
1971	316935	401570	349759
1972	341708	434048	362580
1973	228470	312490	259367
1974	205070	290684	235390
1975	189062	262950	244997
1976	214666	297382	244997
1977	191134	281279	258849
1978	271341	360479	354336
1979	237859	313824	339762
1980	252804	341073	391210
1981	291258	395461	395933
1982	259054	357101	386544

1983	240591	339314	324811
1984	200253	293792	277895
1985	191340	285831	241832
1986	168972	240104	227749
1987	176206	259756	257816
1988	152456	218949	206076
1989	111190	184017	179333
1990	99725	165121	138275
1991	87090	154042	118184
1992	100841	161922	140225
1993	96841	162835	158843
1994	90345	154833	148146
1995	115443	182664	162478
1996	107954	180032	153941
1997	106601	175733	180153
1998	122989	189730	191975
1999	78195	147585	110718
2000	64464	130965	90091
2001	43749	92800	55950
2002	45984	93367	65012
2003	27878	62441	36088
2004	24764	56711	34865
2005	23709	53525	41291
2006	24589	51155	31793
2007	22153	47216	53157
2008	23925	49172	52365
2009	29452	53426	54940
2010	33483	59671	48776
2011		57029	44846
2012		58101	40336
2013		58580	41564
2014		62507	45844
2015			52104

Cod NEArctic

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT/ ICES database	Reconstructed catch (LME)	ICES AFWG 2016 Landings
1946			706000
1947			882017
1948			774295
1949			800122
1950	475422	827714	731982
1951	632076	1017394	827180
1952	608841	1058471	876795
1953	415313	839130	695546
1954	412242	1132420	826021
1955	1215009	1716960	1147841
1956	1424864	1834916	1343068
1957	844113	951067	792557
1958	791204	843073	769313
1959	829177	910696	744607
1960	795248	940007	622042
1961	880412	1011533	783221
1962	929328	1244949	909266
1963	804075	1173355	776337
1964	468535	625096	437695
1965	481484	601182	444930
1966	557662	732425	483711
1967	619352	761668	572605
1968	1102807	1415813	1074084
1969	1230209	1572370	1197226
1970	956049	1294953	933246
1971	729122	884174	689048
1972	648011	791297	565254
1973	834304	1143226	792685
1974	1142944	1565975	1102433
1975	886121	1166932	829377
1976	908007	1140365	867463
1977	945315	1160278	905301
1978	732743	957073	698715
1979	485361	577550	440538

1980	420197	457420	380434
1981	433710	458785	399038
1982	403593	394320	363730
1983	327993	329445	289992
1984	315323	305452	277651
1985	335738	413408	307920
1986	454421	442857	430113
1987	551954	538679	523071
1988	458797	494475	434939
1989	348500	430760	332481
1990	209508	222804	212000
1991	294272	282018	319158
1992	421025	407350	513234
1993	575189	564099	581611
1994	795216	898634	771086
1995	763319	771120	739999
1996	758315	766605	732228
1997	791795	745254	762403
1998	615295	629073	592624
1999	506117	450306	484910
2000	412670	365526	414868
2001	445534	393135	426471
2002	453407	454912	535045
2003	448970	447392	551990
2004	504362	468658	606445
2005	485340	436854	641276
2006	474454	413348	537642
2007	453400	423236	486883
2008	460286	408237	464171
2009	529015	434690	523430
2010	617000	492753	609983
2011		748997	719830
2012		795176	727663
2013		1027051	966209
2014		1044137	986449
2015			864384

Herring North Sea

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT/ ICES database	Reconstructed catch (LME)	ICES HAWG 2017 catch	ICES HAWG 2017 Model catch	ICES HAWG 2017 Model catch high
1947			581760	847461	1050438
1948			502100	688314	828325
1949			508500	714258	860783
1950	1107467	1059261	491700	657368	759496
1951	1220216	1198595	600400	770658	880132
1952	938462	945395	664400	830680	939136
1953	1212080	1210491	698500	842391	949608
1954	1297296	1323209	762900	918043	1034084
1955	1042307	1020238	806400	864581	970436
1956	1158039	1076516	675200	850007	955555
1957	1039728	1109878	682900	784655	878908
1958	804643	1010685	670500	791749	887295
1959	890511	1034189	784500	1140526	1344328
1960	787793	912379	696200	835679	954882
1961	689778	915193	696700	762990	877650
1962	548975	921287	627800	678066	775036
1963	640091	1053638	716000	654744	773386
1964	818016	1111751	871200	930056	1063521
1965	1123205	1226595	1168800	1234282	1423310
1966	876132	1035506	895500	972864	1098480
1967	620823	918302	695500	832343	940459
1968	685951	950420	717800	820771	952604
1969	569250	778592	546700	552937	638150
1970	608619	804625	563100	534454	618795
1971	549308	752852	520100	542531	624182
1972	525455	703754	497500	469301	544109
1973	533374	757943	484000	445521	512612
1974	270317	446944	275100	273211	310692
1975	295308	426786	312800	269682	318322
1976	161497	256460	174800	150995	186143
1977	44191	179312	46000	59755	72132
1978	6497	127640	11000	51226	71253

1979	5871	95838	25100	64667	90544
1980	13796	112553	70764	80903	94983
1981	39967	190846	174879	159532	195193
1982	47701	208042	275079	271034	332036
1983	190059	372908	387202	402721	479198
1984	235335	423224	428631	453160	514873
1985	460769	619933	613780	612314	697089
1986	466327	621120	671488	765282	874334
1987	511212	627419	792058	786226	889216
1988	488402	645551	887686	1033023	1183247
1989	474572	647231	787899	796514	890438
1990	389706	582745	645229	693149	772997
1991	379431	530602	658008	673336	747339
1992	379936	581848	716799	700115	784415
1993	386676	615303	671397	682829	766083
1994	371712	534266	568234	600790	679435
1995	407300	636569	579371	549630	626257
1996	168474	312388	275098	294196	338010
1997	197185	282552	264313	281813	321953
1998	252783	337138	391628	386930	435052
1999	251375	343495	363163	363306	412995
2000	261148	338053	388157	377377	422607
2001	247984	336038	374065	384616	431904
2002	235801	332237	394709	407176	461754
2003	350371	432536	482281	496828	558352
2004	415400	467401	587698	587717	661710
2005	485505	563904	663813	641138	731736
2006	416799	472464	514597	509915	577882
2007	306954	358609	406482	369165	431325
2008	177489	222975	257870	253470	289513
2009	183223	207328	168443	181498	209308
2010	192358	196344	187611	193300	217040
2011		201230	226478	234685	263800
2012		347673	434710	416649	473913
2013		421593	511416	482145	545462
2014		380956	517356	505347	569194
2015			494099	474967	547312
2016					

Plaice North Sea

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT / ICES database	Reconstructed catch (LME)	ICES WGNSSK 2016 catch
1950	67380	110305	
1951	66533	110561	
1952	70778	119805	
1953	78883	128873	
1954	66965	111776	
1955	63315	106660	
1956	63881	108345	
1957	69272	115600	78443
1958	72429	120501	88191
1959	78324	137462	109164
1960	86289	149978	117334
1961	85783	161886	118474
1962	88600	173937	125375
1963	108158	199155	148376
1964	110368	201407	147571
1965	96927	173788	140223
1966	100130	186127	166552
1967	100647	186332	163365
1968	108838	209890	139521
1969	121652	227746	142820
1970	129737	240109	159982
1971	113921	222681	136939
1972	122524	241765	142475
1973	130214	247294	143783
1974	112516	223978	157485
1975	108545	221603	195235
1976	107982	224408	166917
1977	107039	229491	176689
1978	92718	190083	159639
1979	107877	213810	213282
1980	101248	204895	171844
1981	95323	200799	174264
1982	112936	239471	205280
1983	102667	215036	220262

1984	115904	235659	236588
1985	148312	256635	232387
1986	127902	254416	308831
1987	130795	239436	359283
1988	138413	237876	324975
1989	152408	252103	286684
1990	156261	248443	240678
1991	143564	230056	238212
1992	123482	197418	193776
1993	115277	186704	163522
1994	109679	181896	145710
1995	96410	163883	131176
1996	80033	135415	143435
1997	81483	132283	193103
1998	70366	117780	183561
1999	77993	135303	160702
2000	82134	134139	135065
2001	79579	134861	193221
2002	69612	114183	134277
2003	65406	111206	153997
2004	61064	102099	127989
2005	52735	90454	119046
2006	55833	94997	131303
2007	49147	86693	100949
2008	47747	84349	105329
2009	52308	92706	108262
2010	59831	109263	116910
2011		109056	118100
2012		117206	141932
2013		124349	126247
2014		114372	133623
2015			134460
2016			136929

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT/ ICES database	Reconstructed catch (LME)	ICES WGWIDE 2017 catch
1950	83974	76321	
1951	107329	88273	
1952	101097	89576	
1953	98283	86137	
1954	92739	84053	
1955	108563	93031	
1956	113609	87335	
1957	152911	111998	
1958	133325	105199	
1959	135570	110933	
1960	155020	128315	
1961	157691	121802	
1962	156173	117101	
1963	133992	116784	
1964	169876	147511	
1965	294408	256547	
1966	623801	636918	
1967	1029885	1085528	
1968	905522	956861	
1969	834501	848006	
1970	470495	415839	
1971	377183	311005	
1972	367395	258037	
1973	597547	438657	
1974	637042	438894	
1975	797472	402910	
1976	829015	490052	
1977	601578	565931	
1978	676517	687229	
1979	718212	721002	
1980	620075	648212	734911
1981	592975	611177	754476
1982	577505	584590	717259
1983	537047	533388	671638

1984	615908	640323	641928
1985	536534	553744	614275
1986	536981	508695	602128
1987	616195	628408	654805
1988	626322	635946	680492
1989	578840	585652	589509
1990	583544	540967	627511
1991	611679	618064	667883
1992	734436	702862	760351
1993	790417	798201	825036
1994	804850	786349	821395
1995	760073	678557	755800
1996	516119	477245	563611
1997	517193	486928	569613
1998	626549	581930	666664
1999	584817	568896	640311
2000	654838	639992	738608
2001	660173	654830	737462
2002	684833	680439	772905
2003	599553	608010	679258
2004	587025	598368	660491
2005	447423	422774	549514
2006	420881	400565	481181
2007	474500	484276	586206
2008	547503	521623	623165
2009	631828	593347	737969
2010	831878	655653	875515
2011		747089	946661
2012		718697	892353
2013		685547	931731
2014		1129976	1394454
2015			1208990
2016			

Haddock North Sea

Total landings/estimated catch (tonnes)

Year	FAO/ EUROSTAT/ ICES database	Reconstructed catch (LME)	ICES WGNSSK Landings + discards + bycatch
1950	56429	75979	
1951	56478	74279	
1952	52372	68698	
1953	60380	79476	
1954	70135	91489	
1955	87656	113805	
1956	93917	122186	
1957	105304	135800	
1958	96191	124625	
1959	79670	102640	
1960	66424	89530	
1961	67238	89890	
1962	52419	71871	
1963	64039	90245	
1964	198706	290672	
1965	221582	302785	
1966	269169	244174	
1967	167435	173963	
1968	139469	184394	
1969	639195	534442	
1970	671833	435823	
1971	258220	253530	
1972	213556	233569	407970
1973	196079	189814	344861
1974	193430	192903	396835
1975	174164	180354	495079
1976	204603	227887	402360
1977	150678	181919	240393
1978	89437	121244	146733
1979	86602	116532	149190
1980	104391	154744	202674
1981	133076	196120	226530

1982	174450	254295	256136
1983	164553	241126	253236
1984	168208	196674	247297
1985	133902	249388	247317
1986	166660	236738	223843
1987	109270	153216	195106
1988	105164	150690	180062
1989	64269	92324	127703
1990	43216	64879	86742
1991	44453	62359	97204
1992	50708	74476	134970
1993	80020	106491	180145
1994	86812	112452	169385
1995	75441	99177	168816
1996	74920	100108	204822
1997	73103	97790	169954
1998	72737	97366	161972
1999	63856	82241	123406
2000	46662	62077	126823
2001	39770	58871	173353
2002	54097	75217	155173
2003	42205	54821	74407
2004	47322	58081	72470
2005	30934	37626	64085
2006	36449	44560	66963
2007	30676	38668	67371
2008	30434	37567	47760
2009	31326	38298	47968
2010	27953	34269	45442
2011		35724	49661
2012		40444	43195
2013		44970	47093
2014		41125	46298
2015			41592